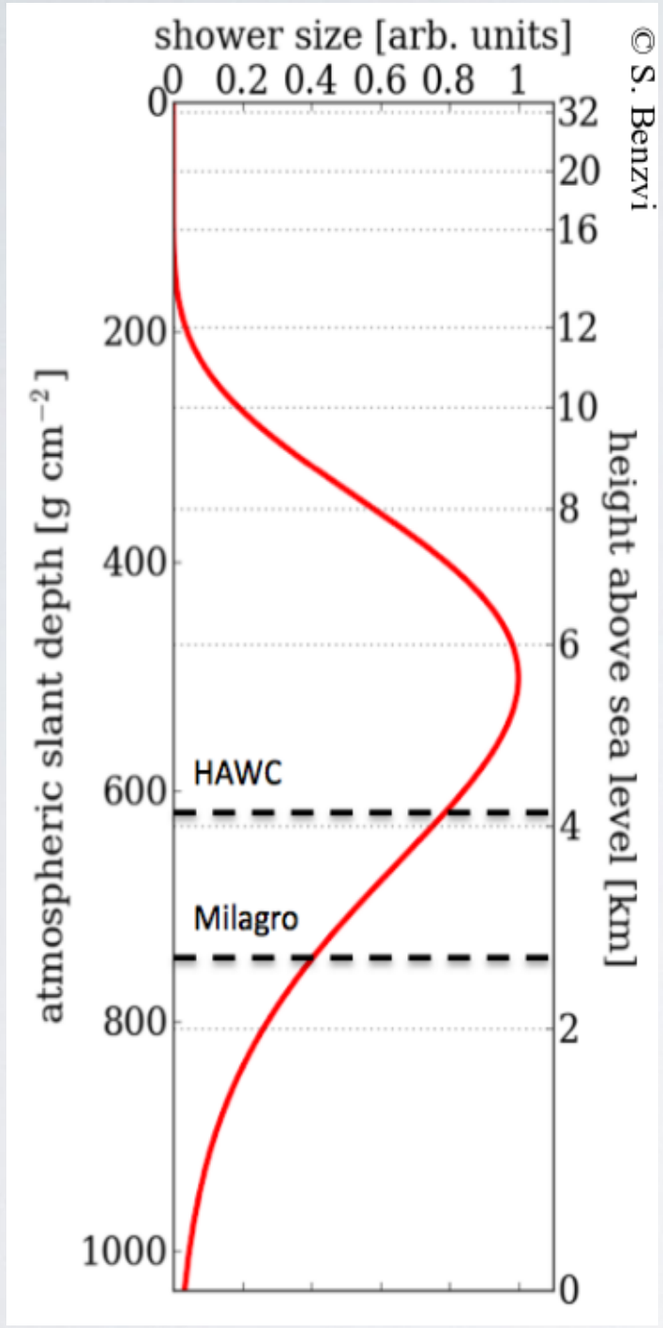
Gamma-ray astronomy across 6 decades of energy: synergy between Fermi, IACTs, and HAWC

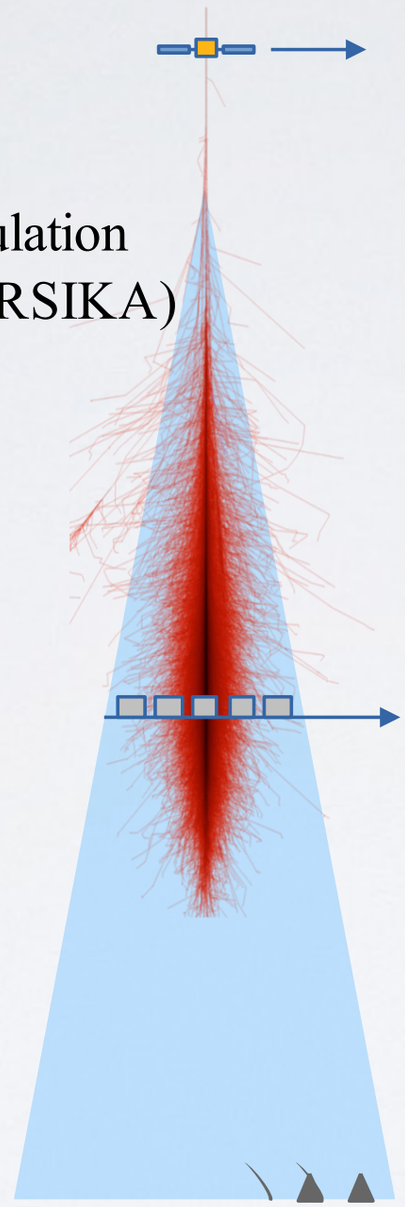
C. Michelle Hui, NASA/MSFC

7th International Fermi Symposium

Oct 18, 2017

Gamma-Ray Observatories





Satellite Detector

Wide Field of View, Continuous Operations

Extensive Air Shower (EAS) Detector

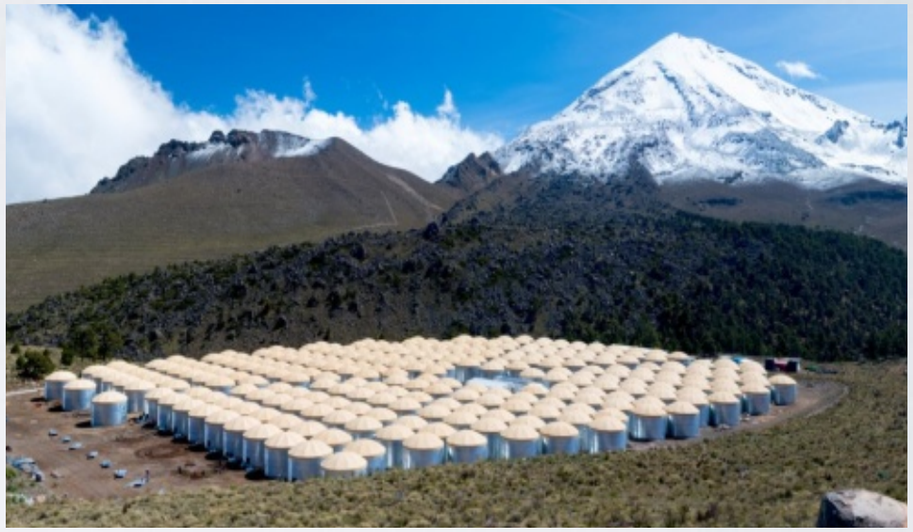
Imaging Atmospheric Cherenkov Telescope (IACT)

TeV Sensitivity

Gamma-Ray Observatories

FOV

sr



deg

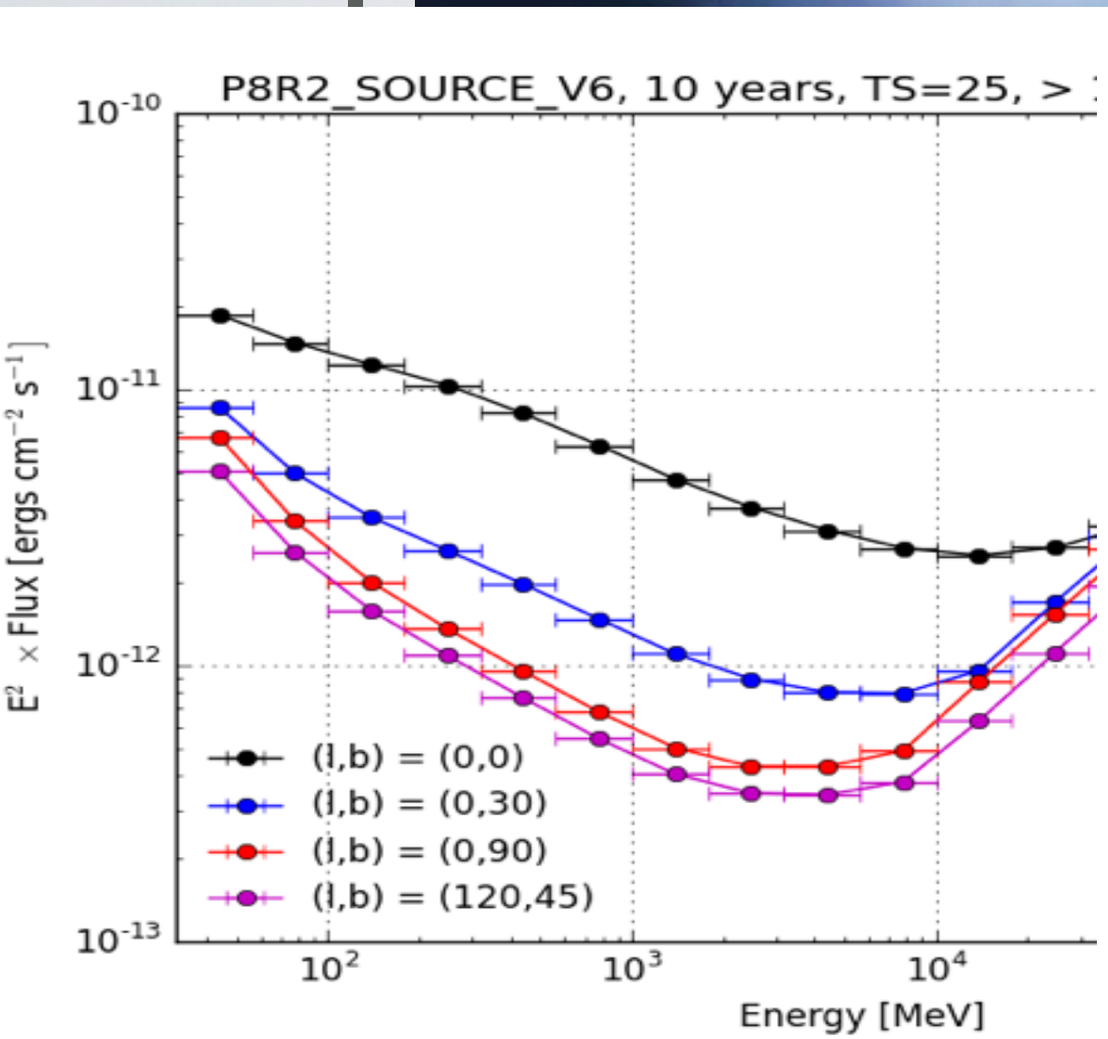
GeV

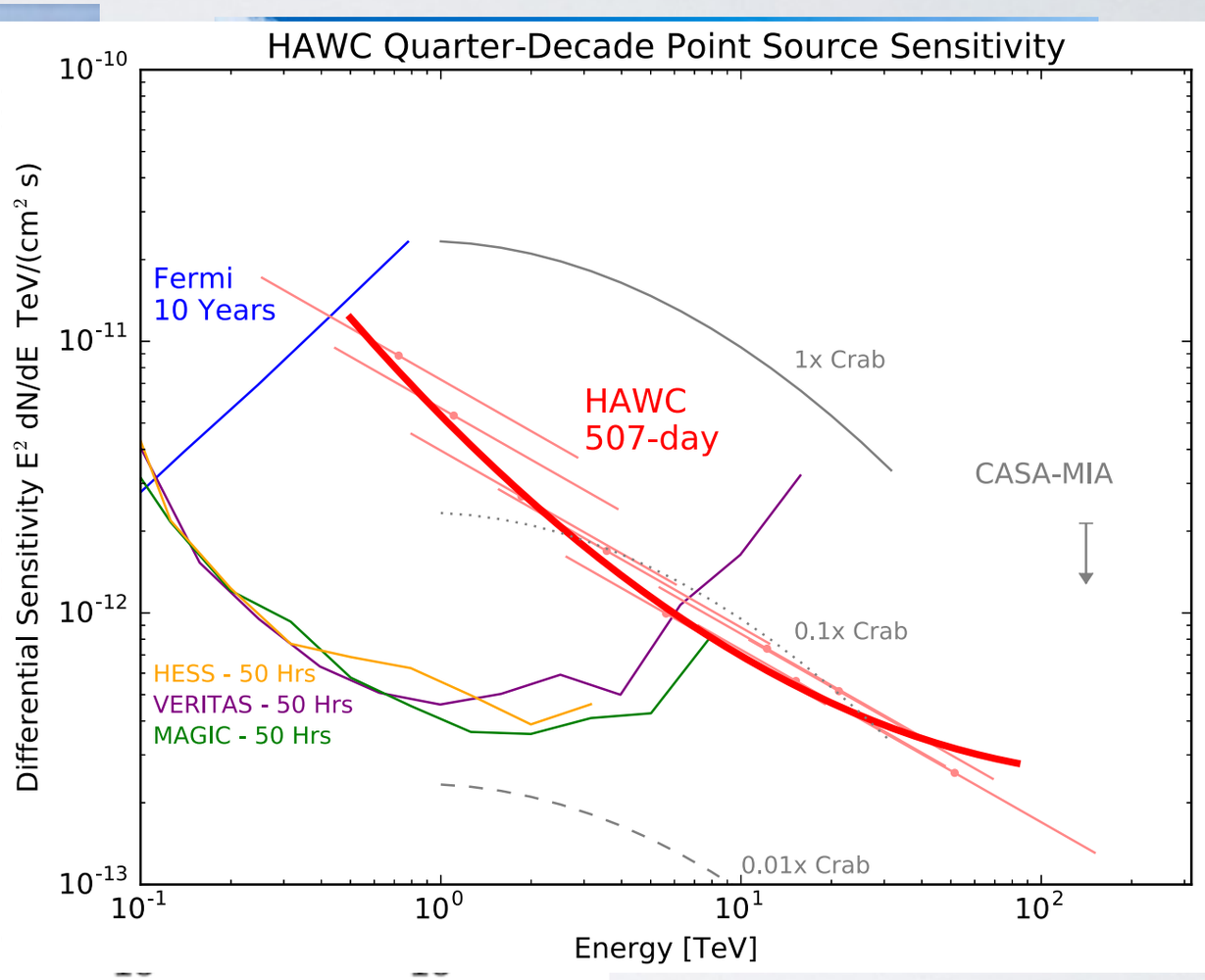
TeV

Energy

Gamma-Ray Observatories

FOV



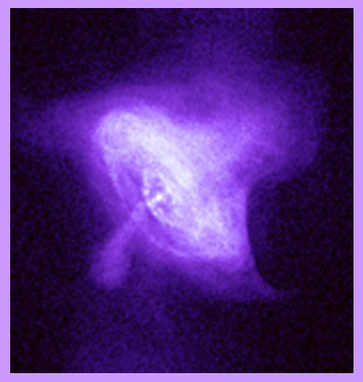


GeV TeV Energy

Gamma-Ray Astrophysics

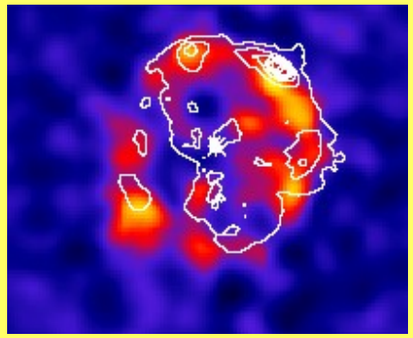
Galactic

Pulsars Wind Nebula

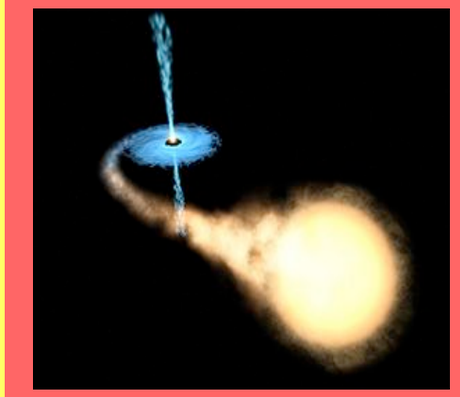


Pulsars

Supernova Remnant

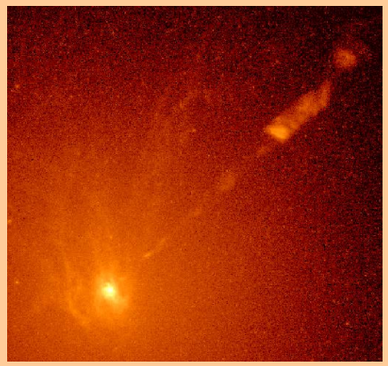


X-ray Binaries



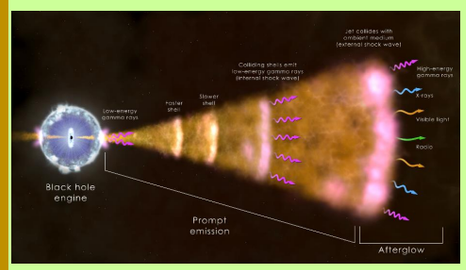
Extragalactic

Active Galactic Nuclei

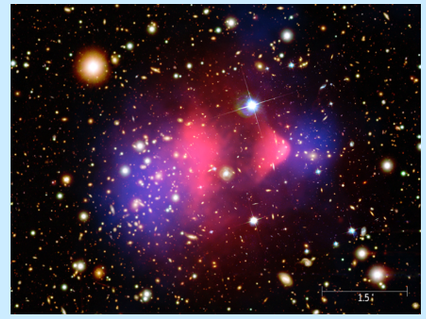


Starburst Galaxies

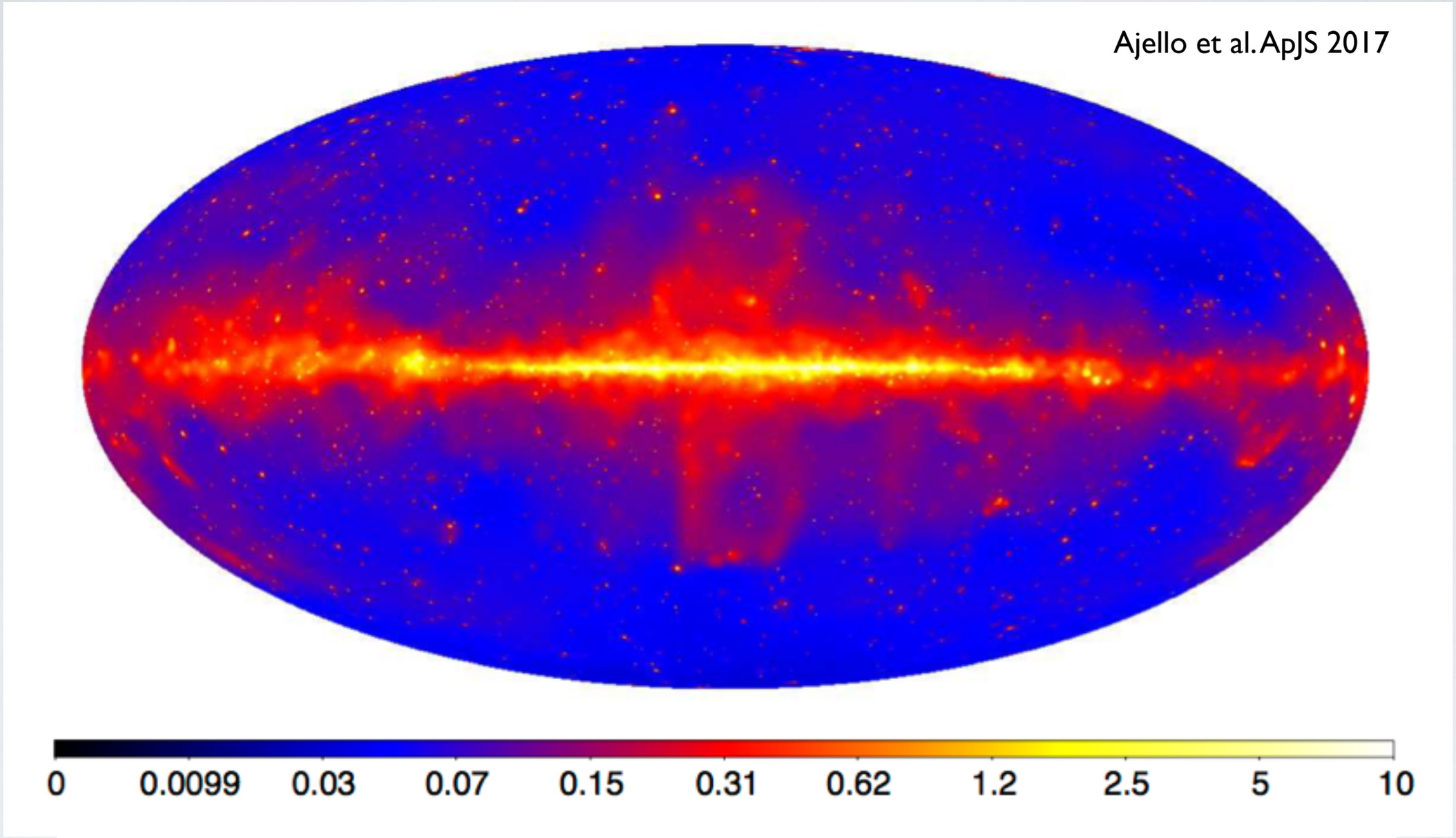
Gamma-Ray Burst



Indirect Dark Matter



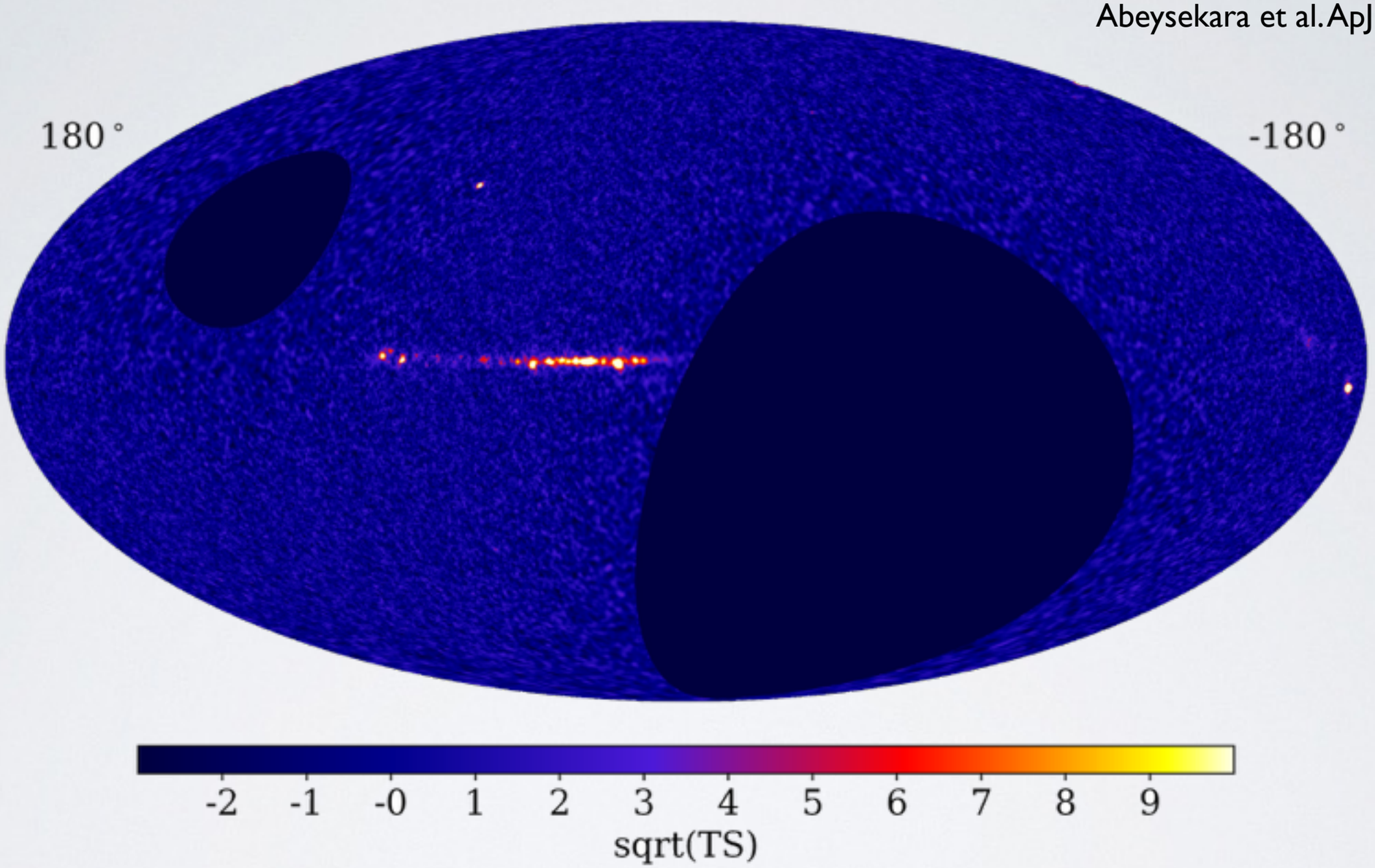
GeV - TeV Sky Survey



Fermi-LAT count map 10 GeV — 2 TeV with >1500 objects in 84 months of data.

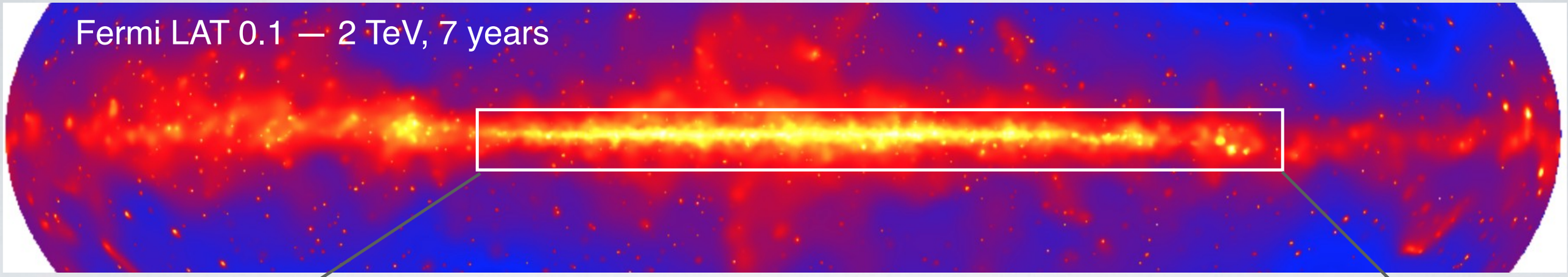
TeV Sky Survey

Abeysekara et al. ApJ 2017

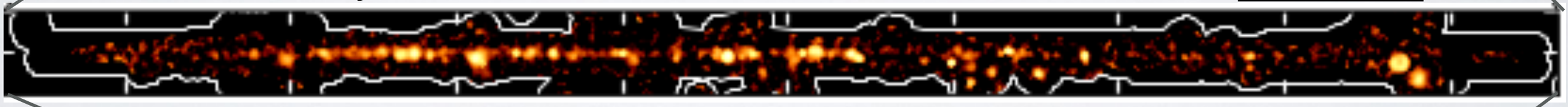


- HAWC TeV skymap in 17 months of data
- 39 2HWC sources: 2 blazars, 5 UID off the Galactic plane.

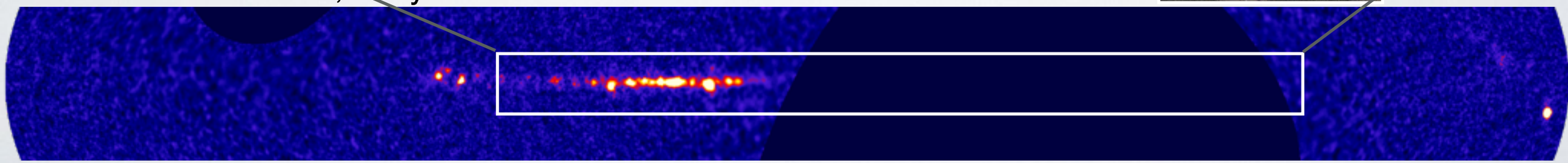
Gamma-ray view of our Galaxy



HESS >1TeV, 10 years



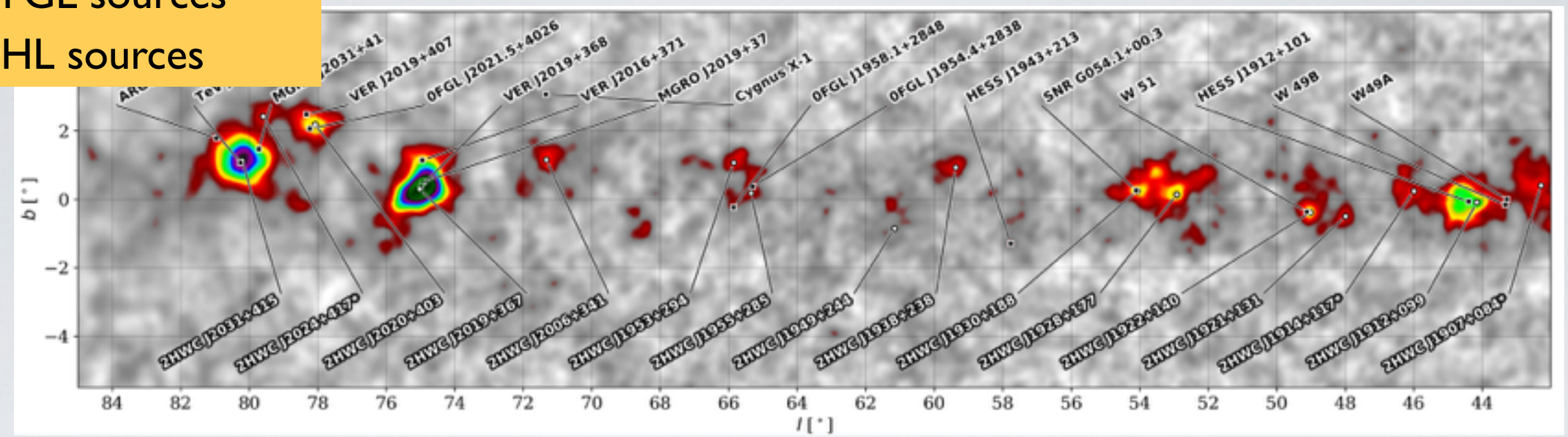
HAWC 0.1—100 TeV, 1.5 year

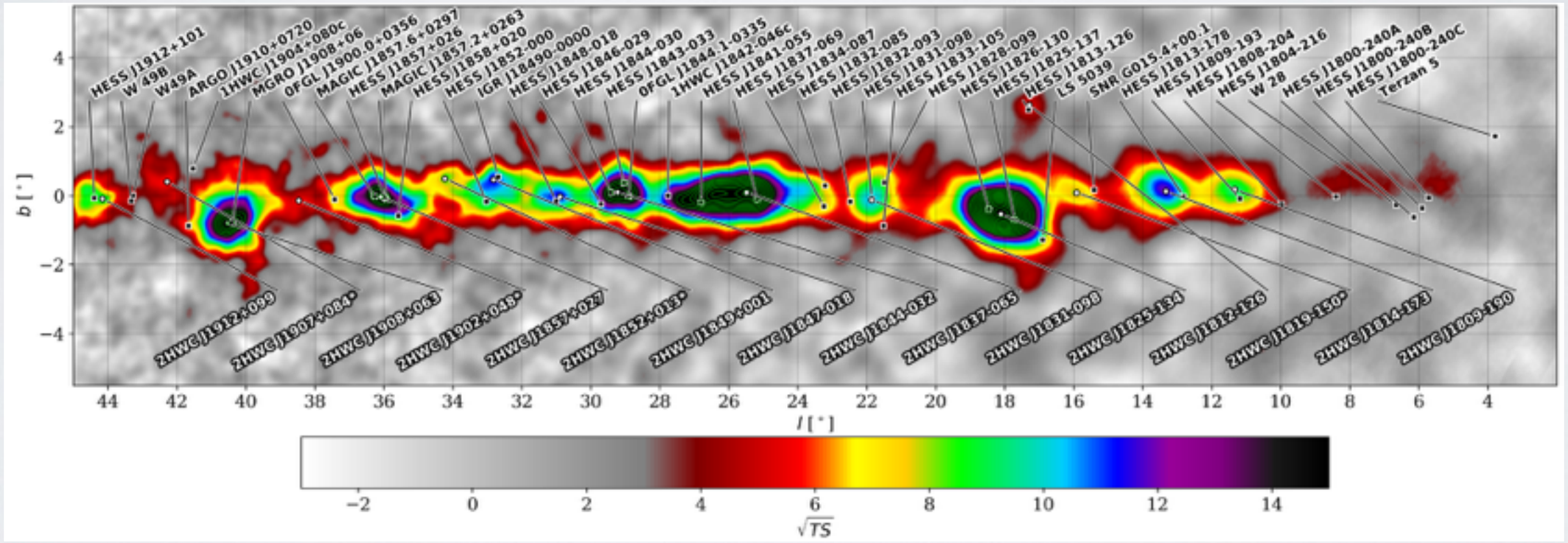


within this area (known extragalactic excluded):

- 150 3FGL sources
- 56 3FHL sources

Galactic Plane



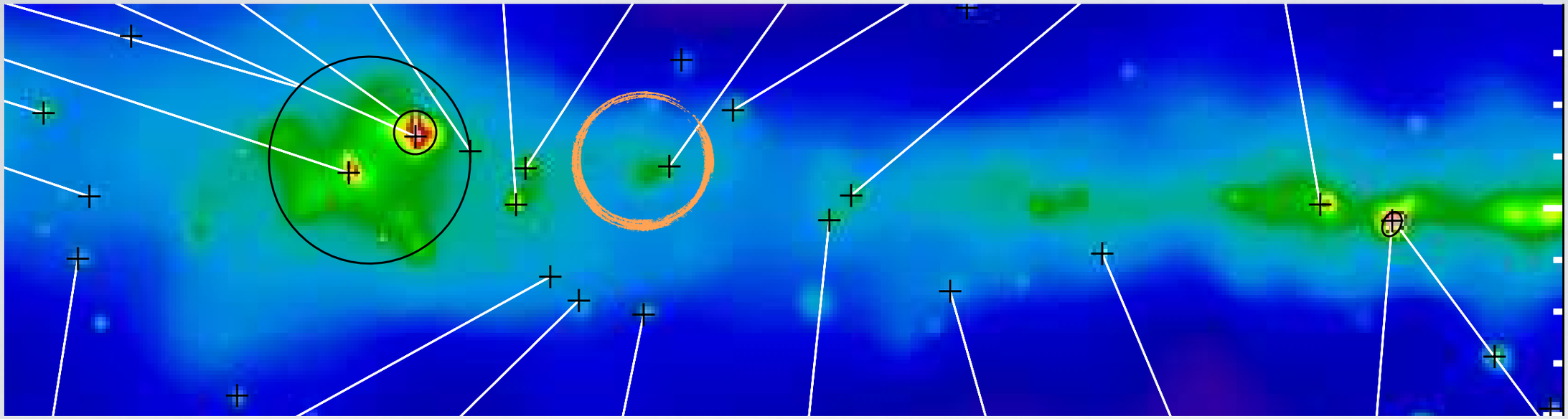


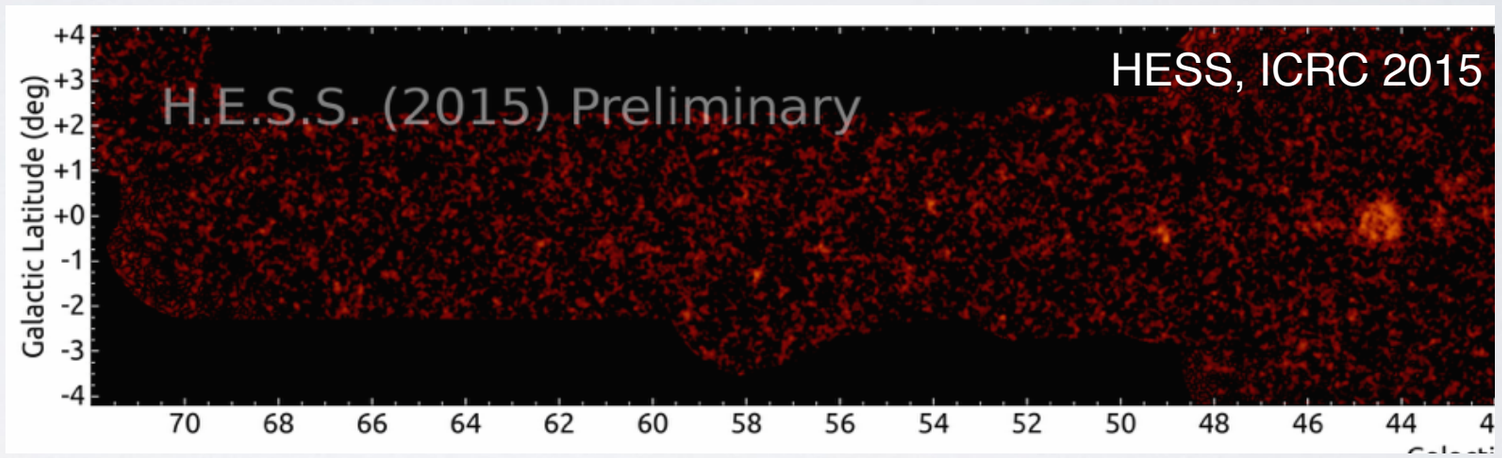
- 30 sources in the Galactic Plane (excluding Crab, Geminga, PSR B0656+14)
  - 16 likely associated with known TeV sources
  - 14 unassociated

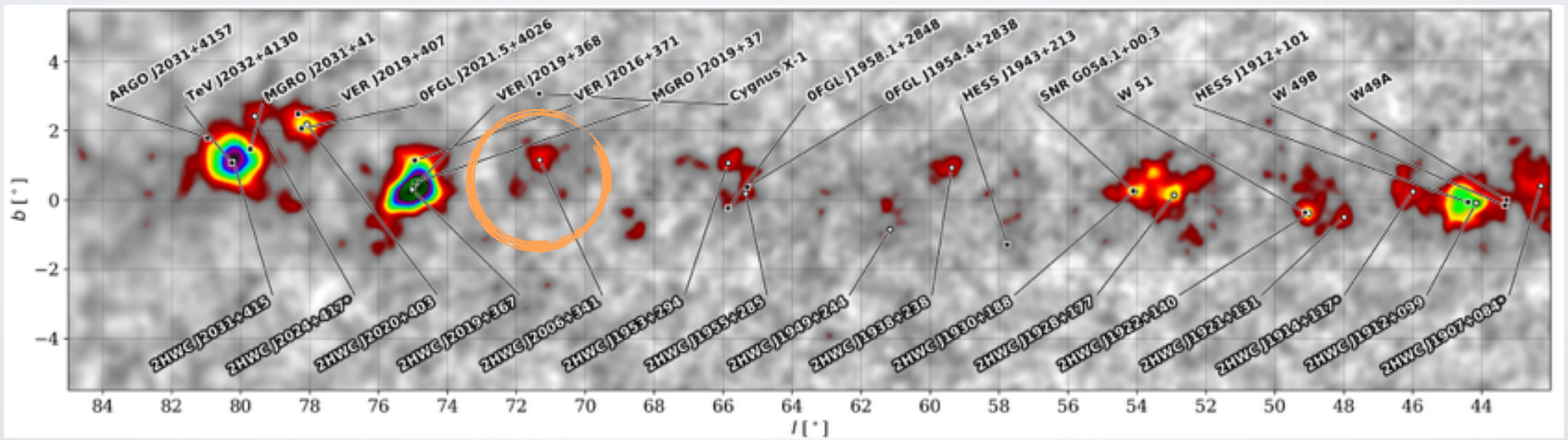
Talk by R. López-Coto. Mon, 16 Oct

Abeysekara et al. ApJ 2017

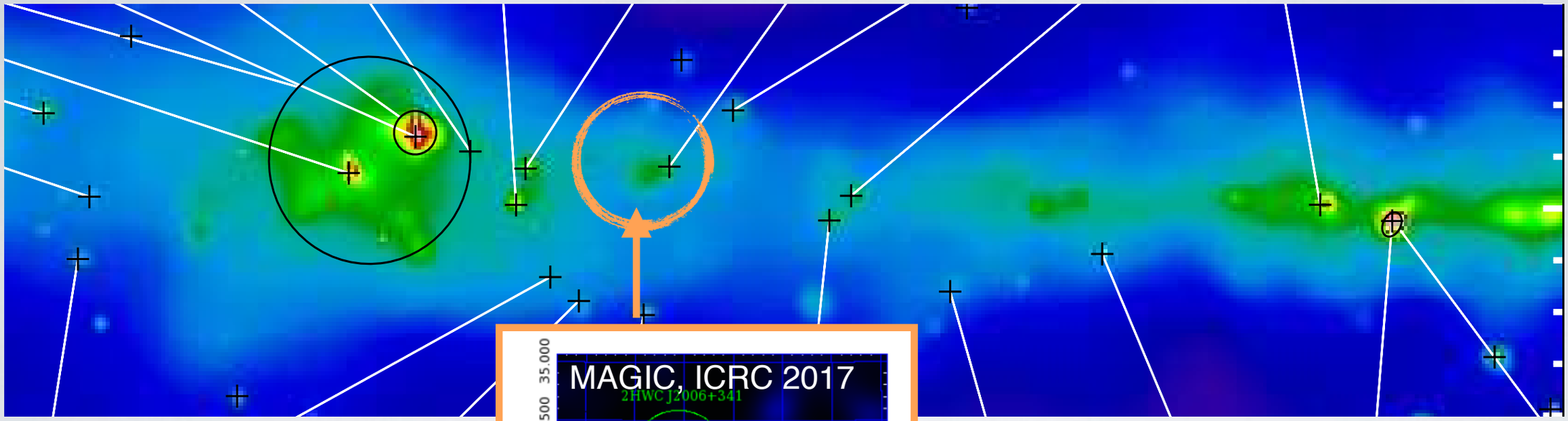
Galactic Plane

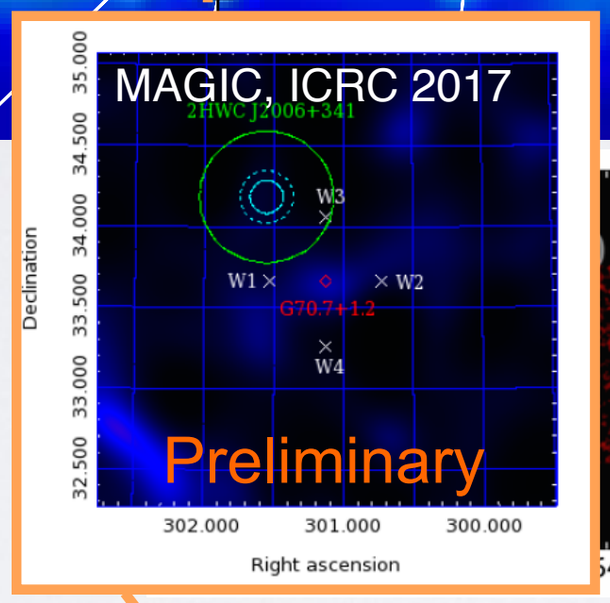


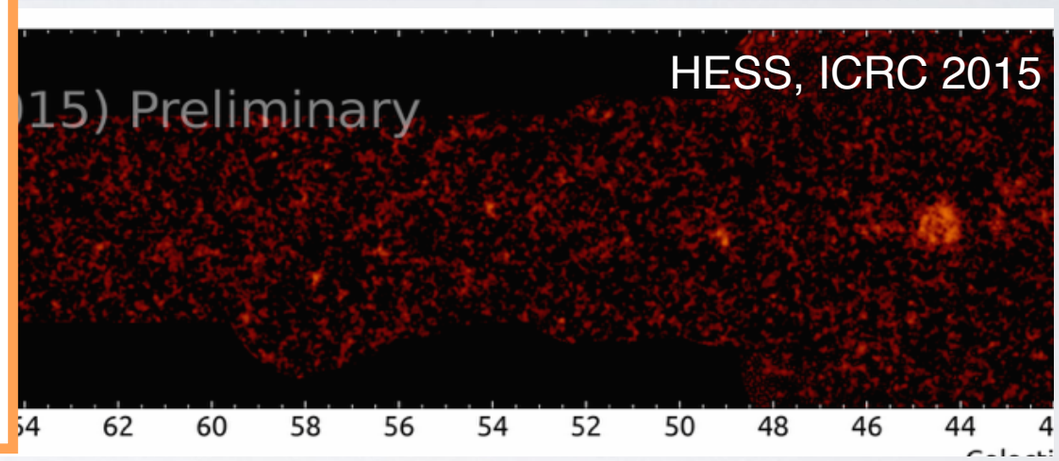


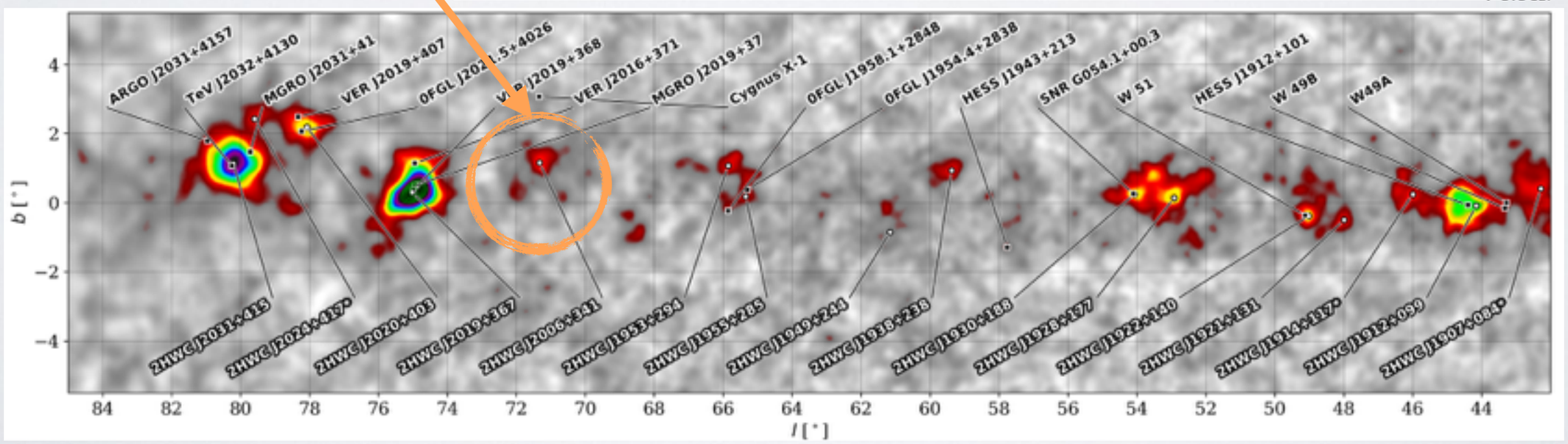


Galactic Plane

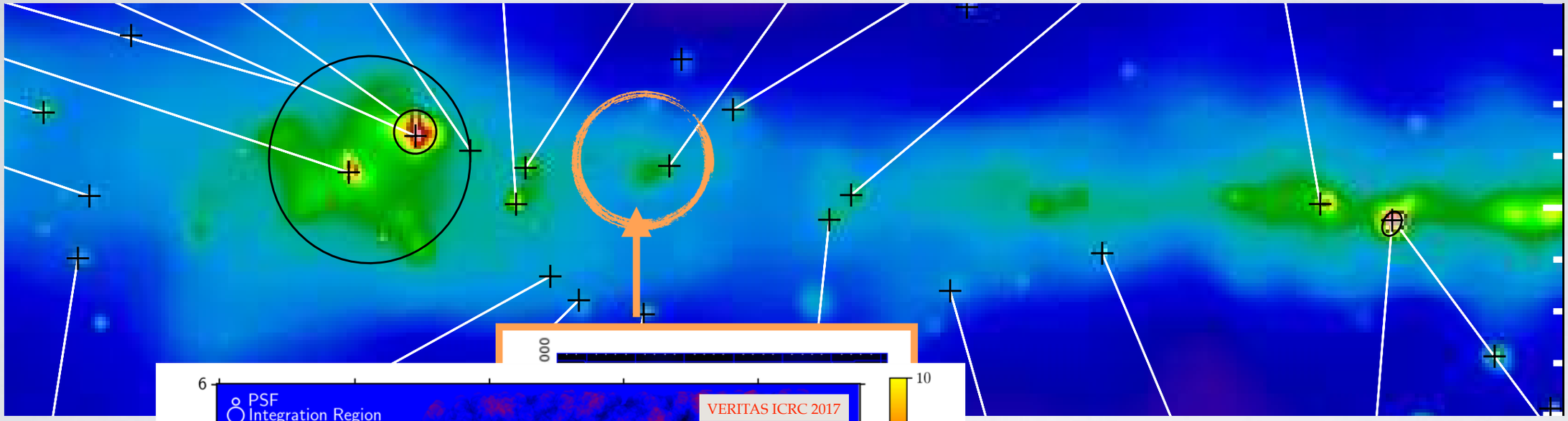


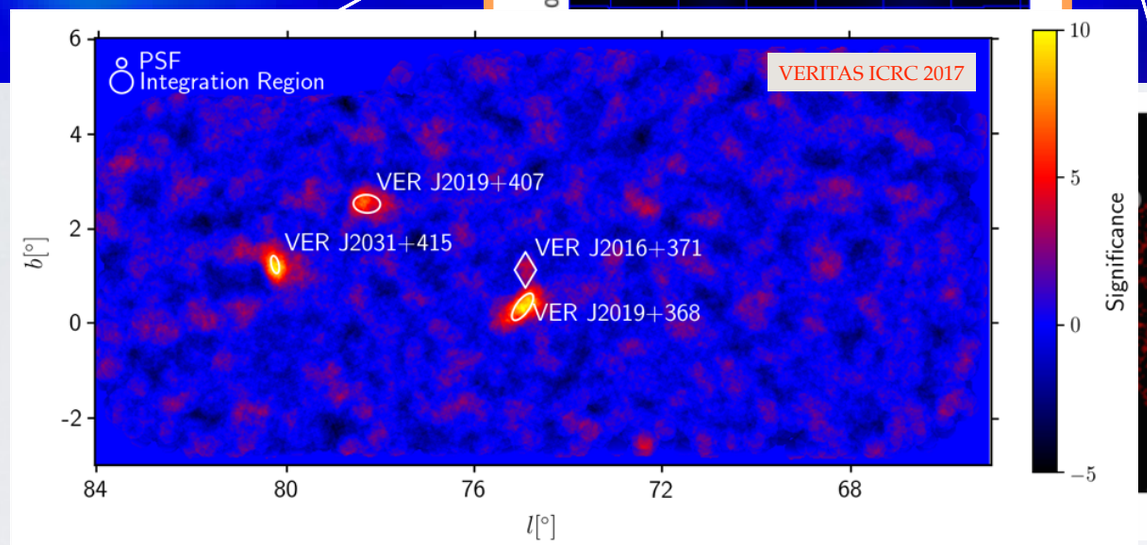


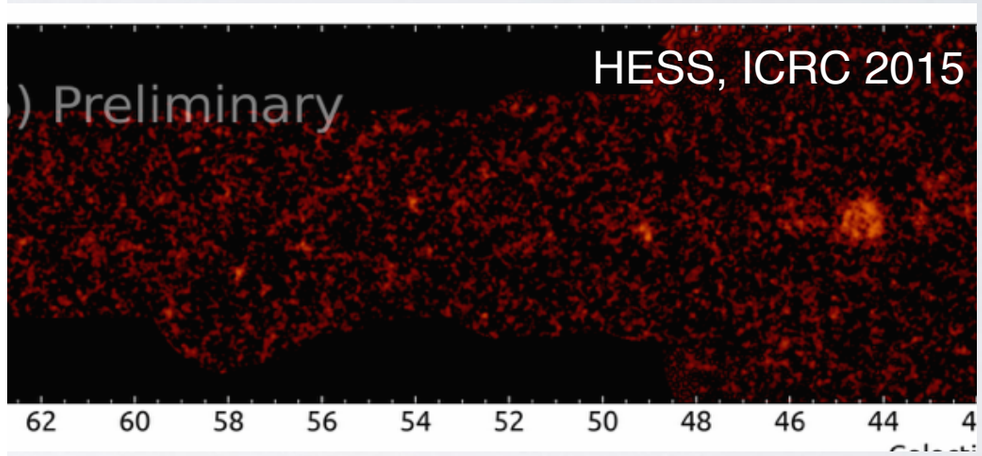


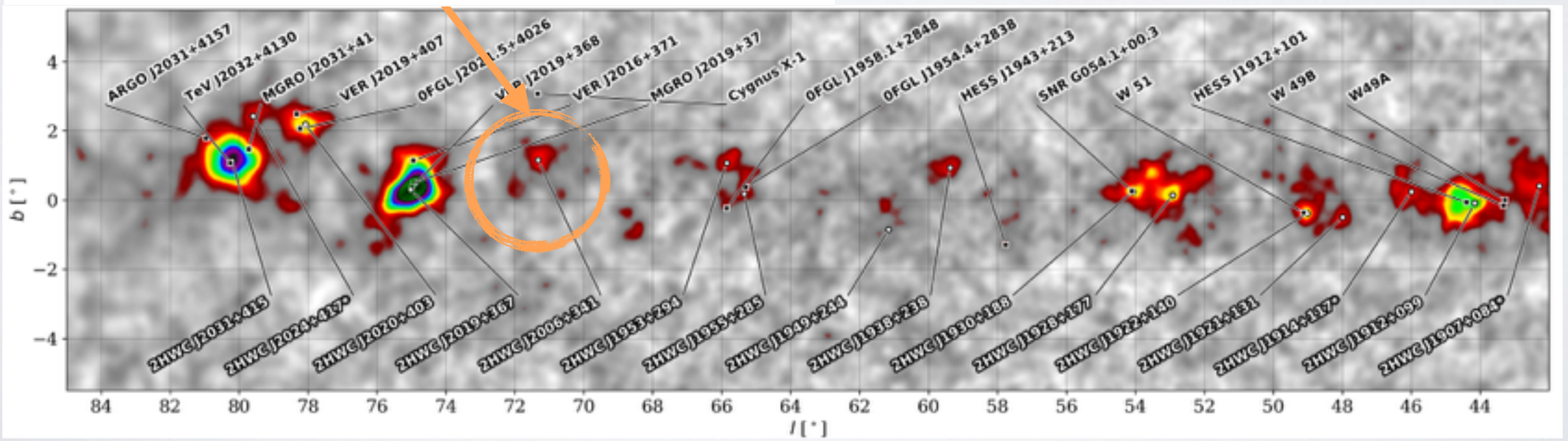


Galactic Plane

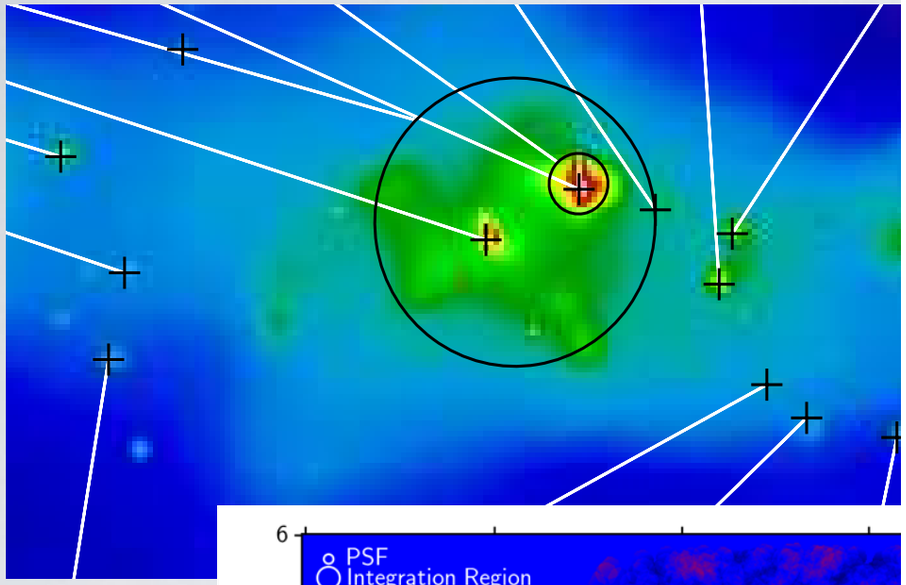


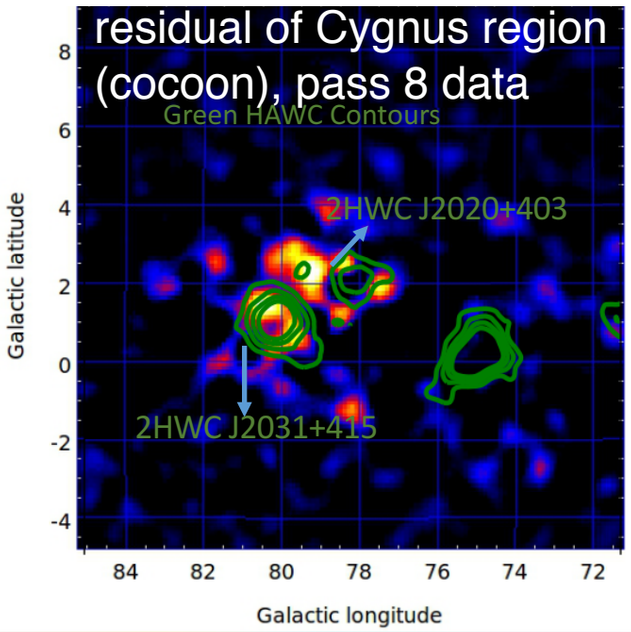


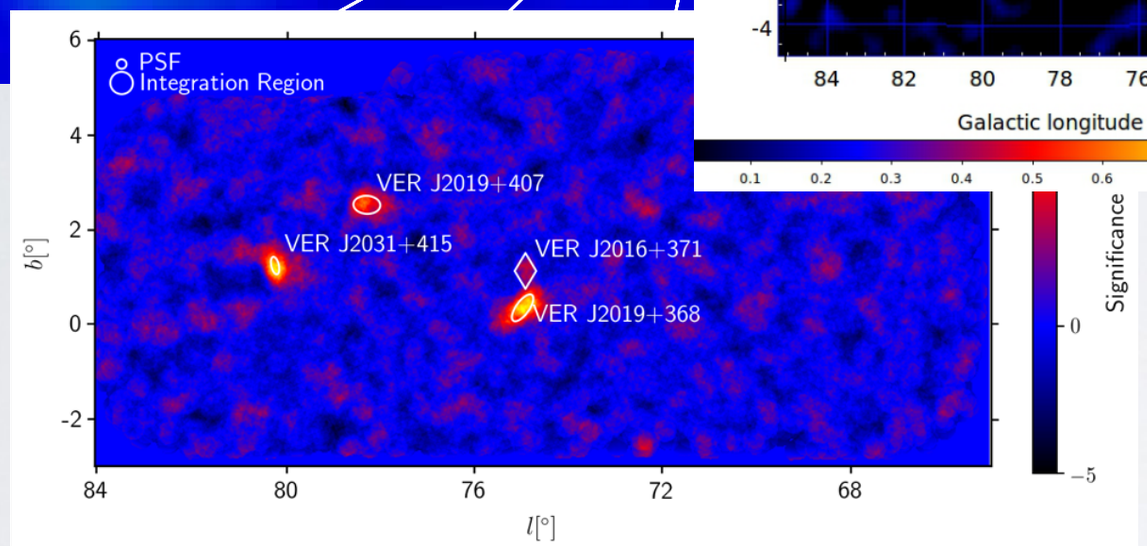


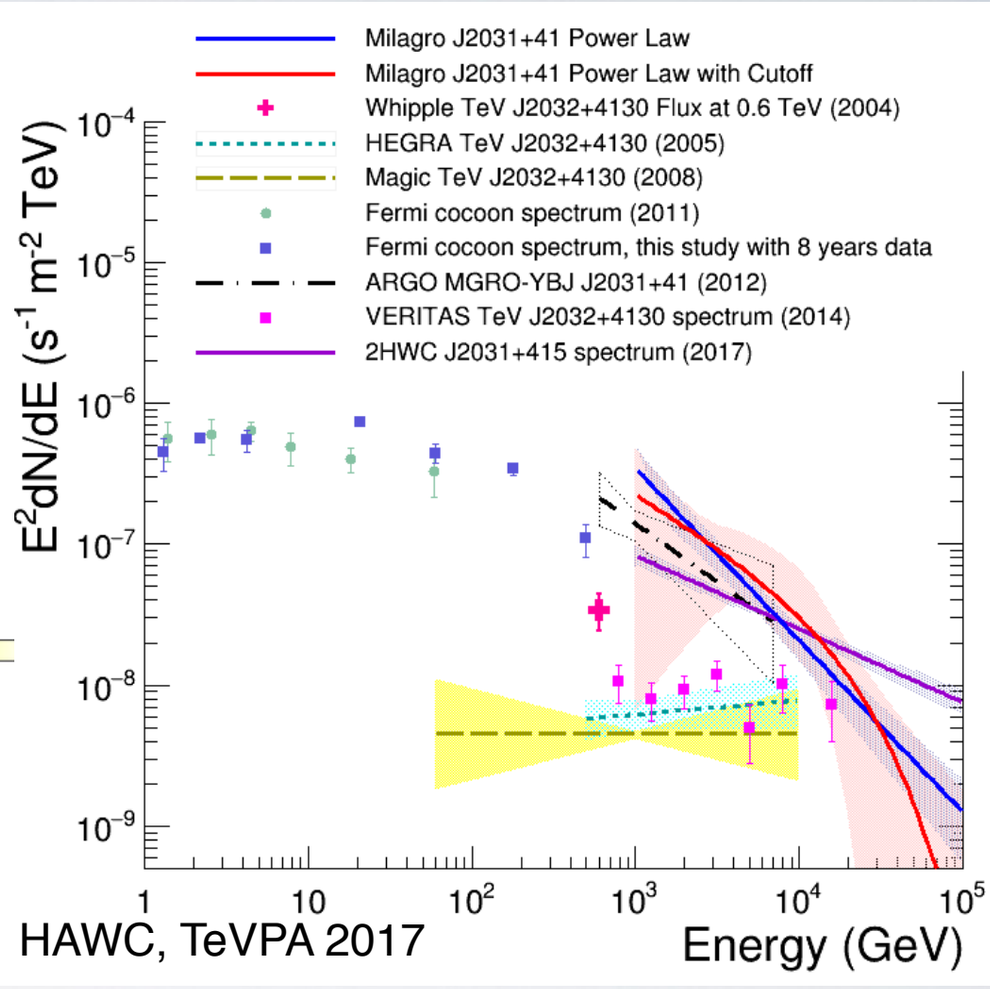


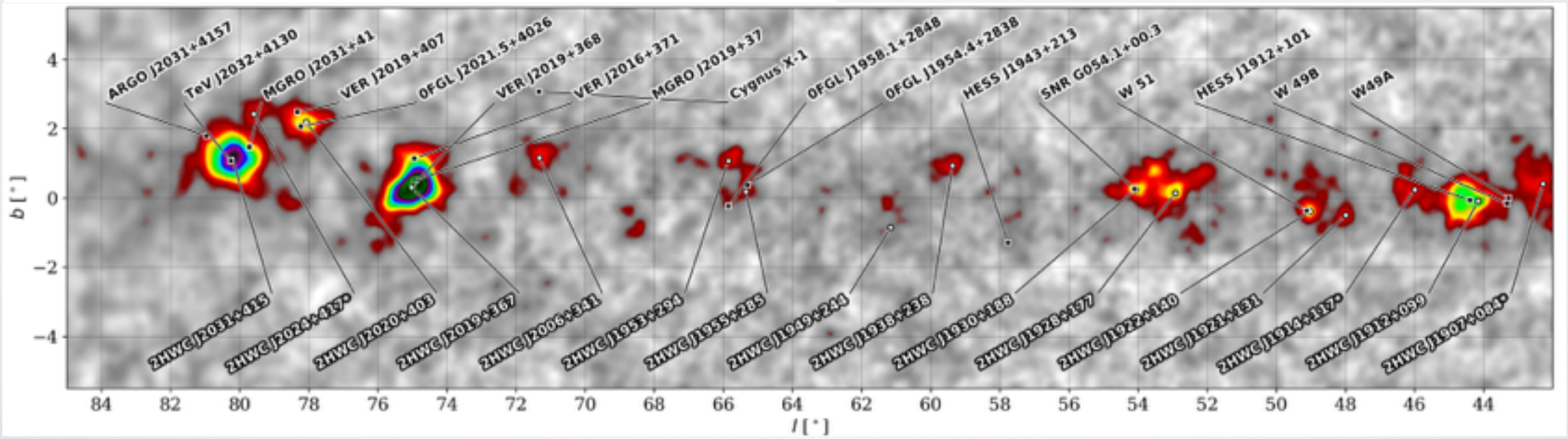
Galactic Plane



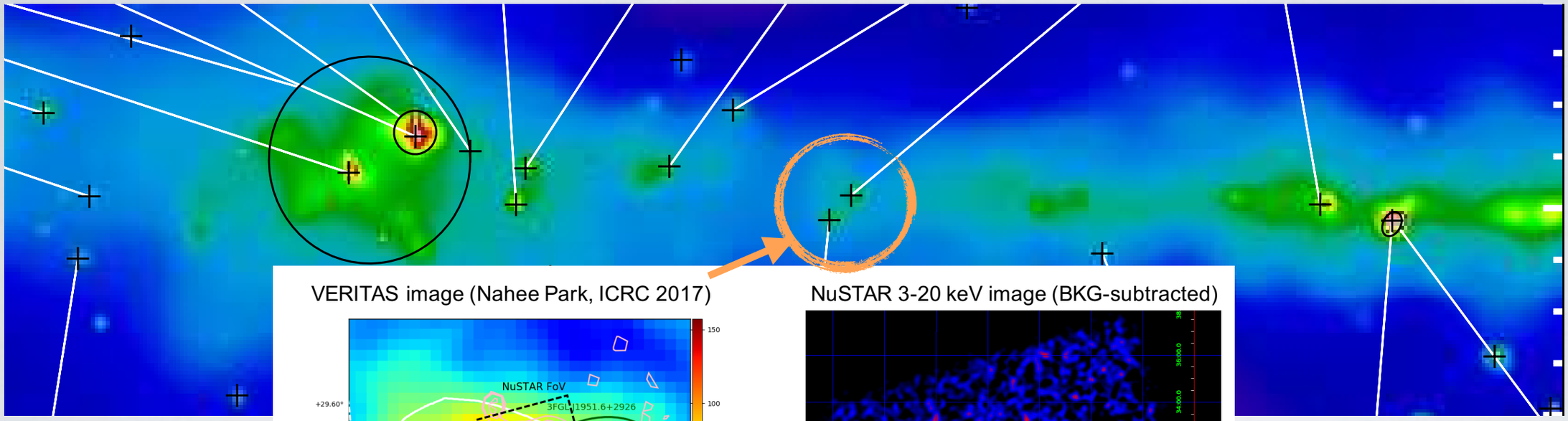




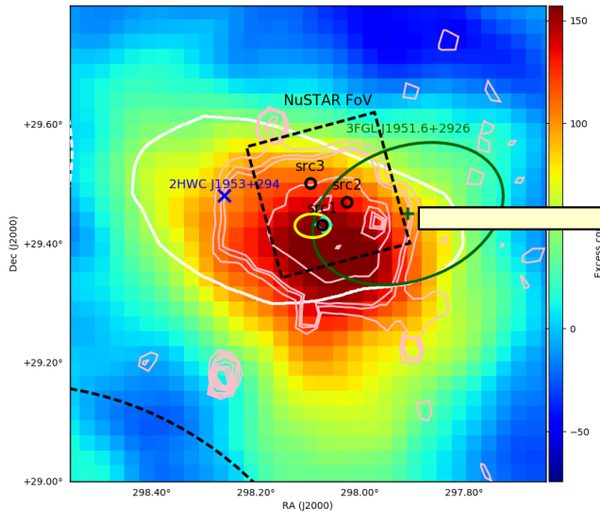




Galactic Plane

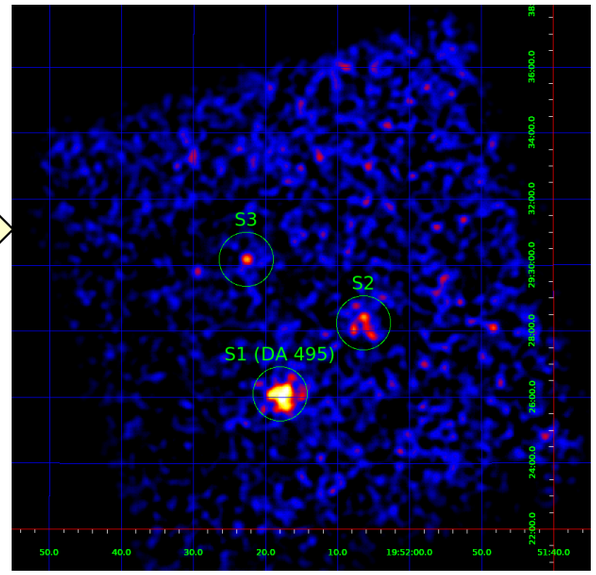


VERITAS image (Nahee Park, ICRC 2017)



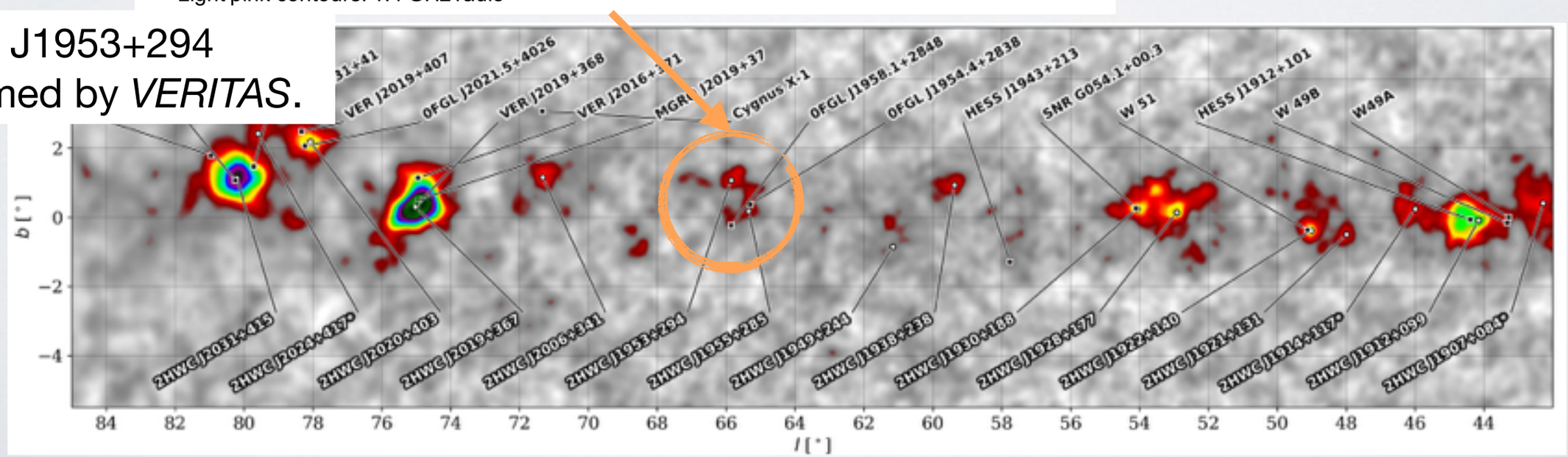
White contours: HAWC 5, 6, 7 standard deviations
Light pink contours: 1.4 GHz radio

NuSTAR 3-20 keV image (BKG-subtracted)

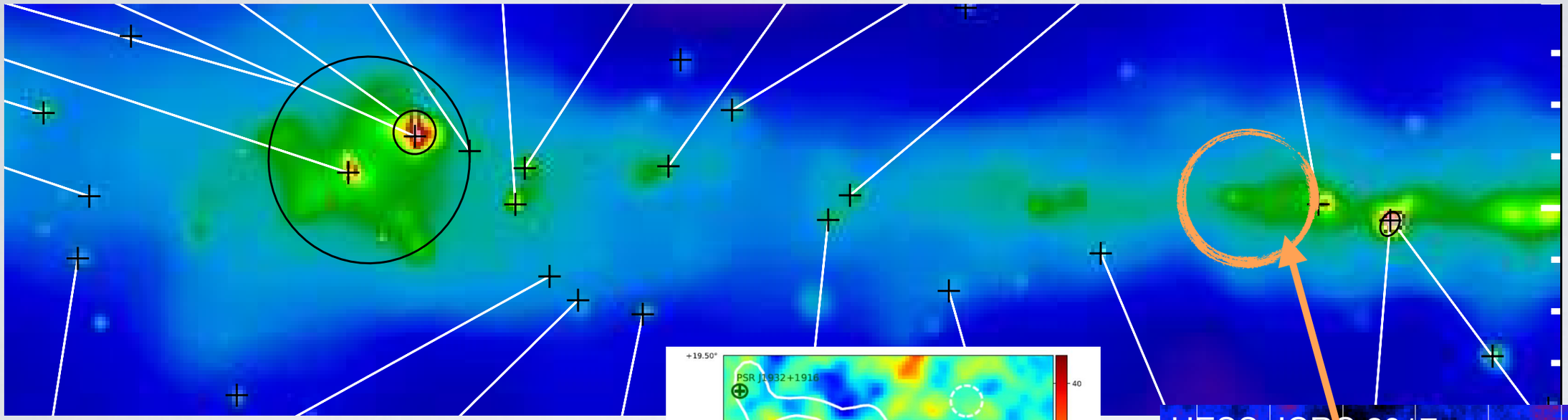


- 60 ksec of NuSTAR observations on June 8 2017.
- 3 sources detected: DA 495 is only likely X-ray counterpart to TeV source.

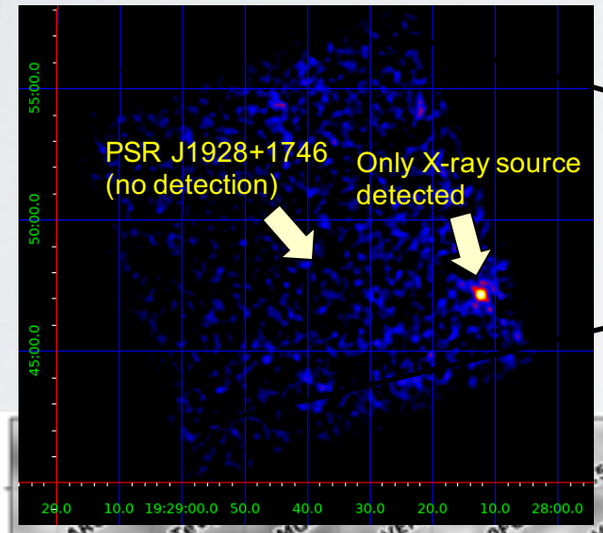
2HWC J1953+294 confirmed by *VERITAS*.

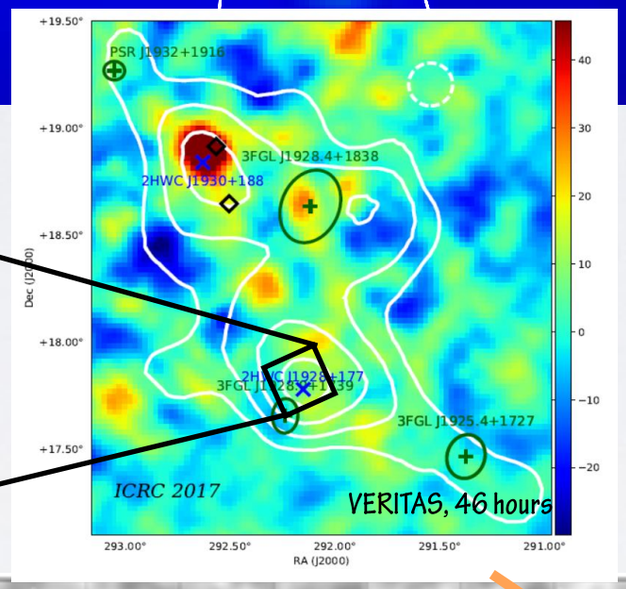


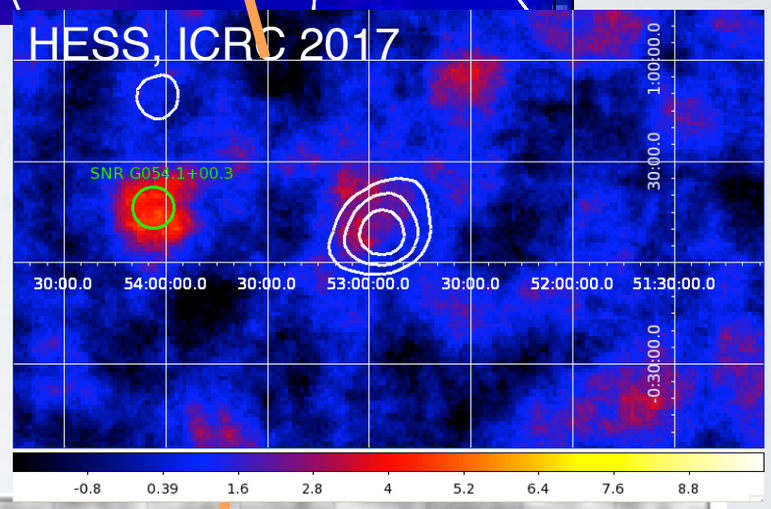
Galactic Plane

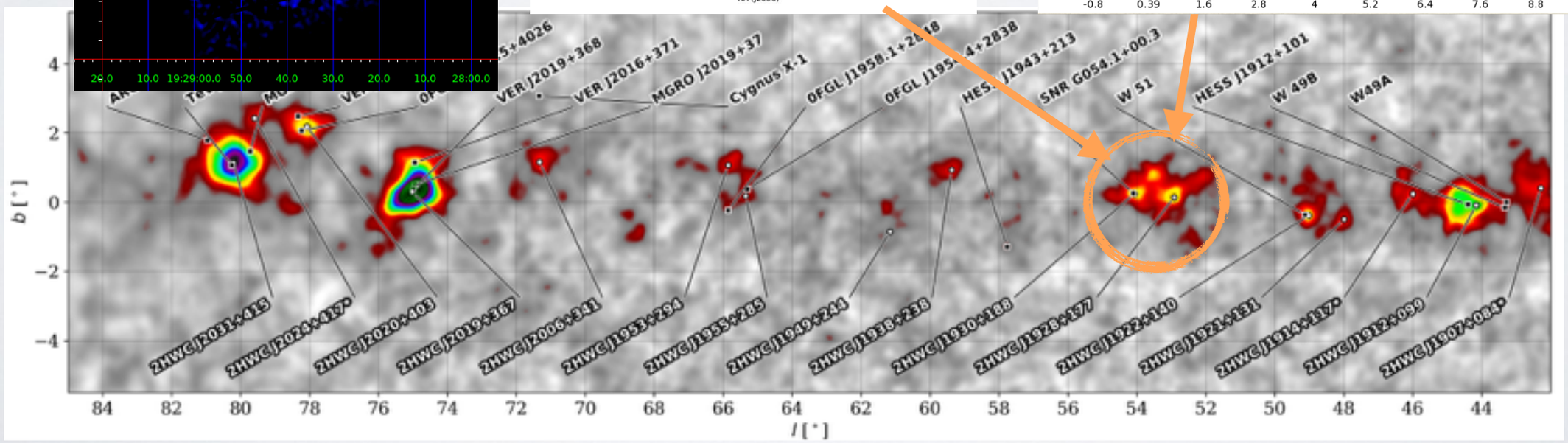


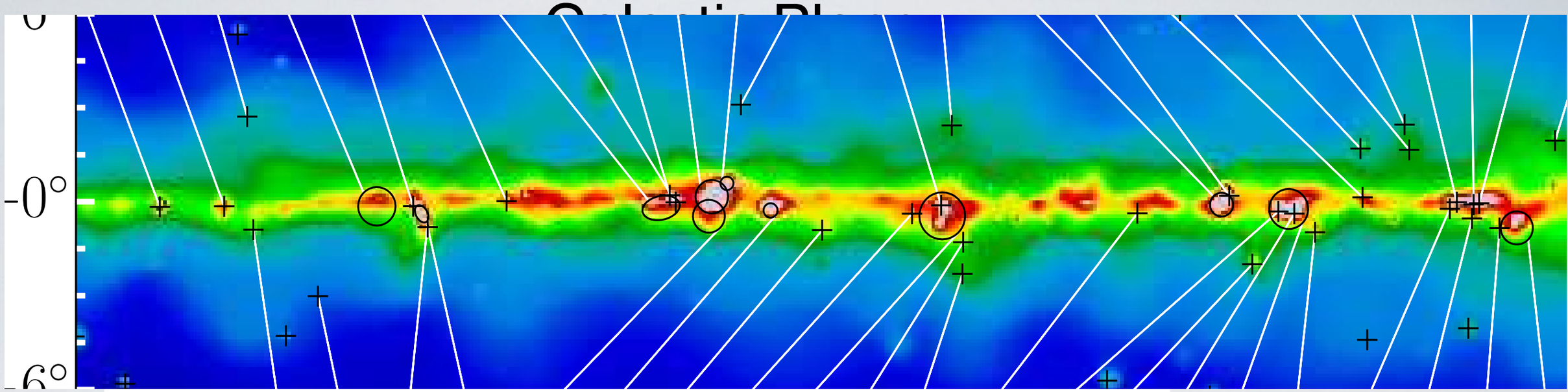
NuSTAR 3-20 keV image (BKG-subtracted)

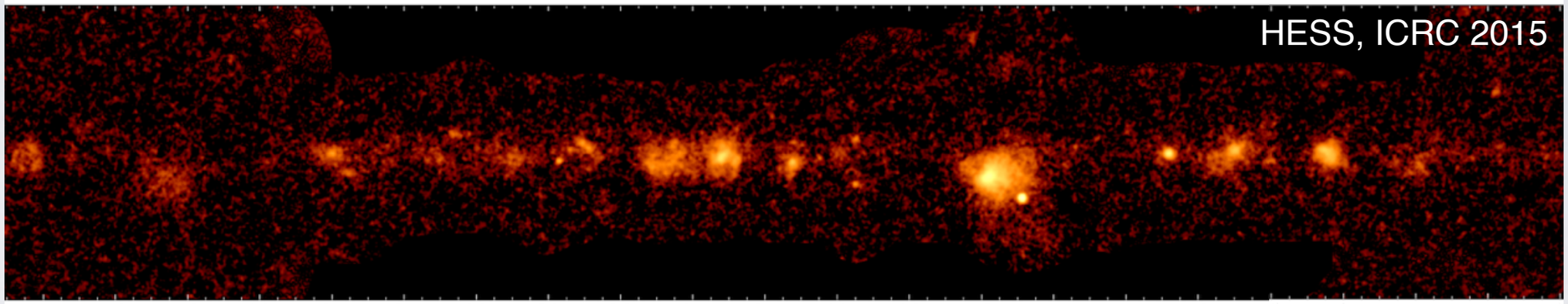


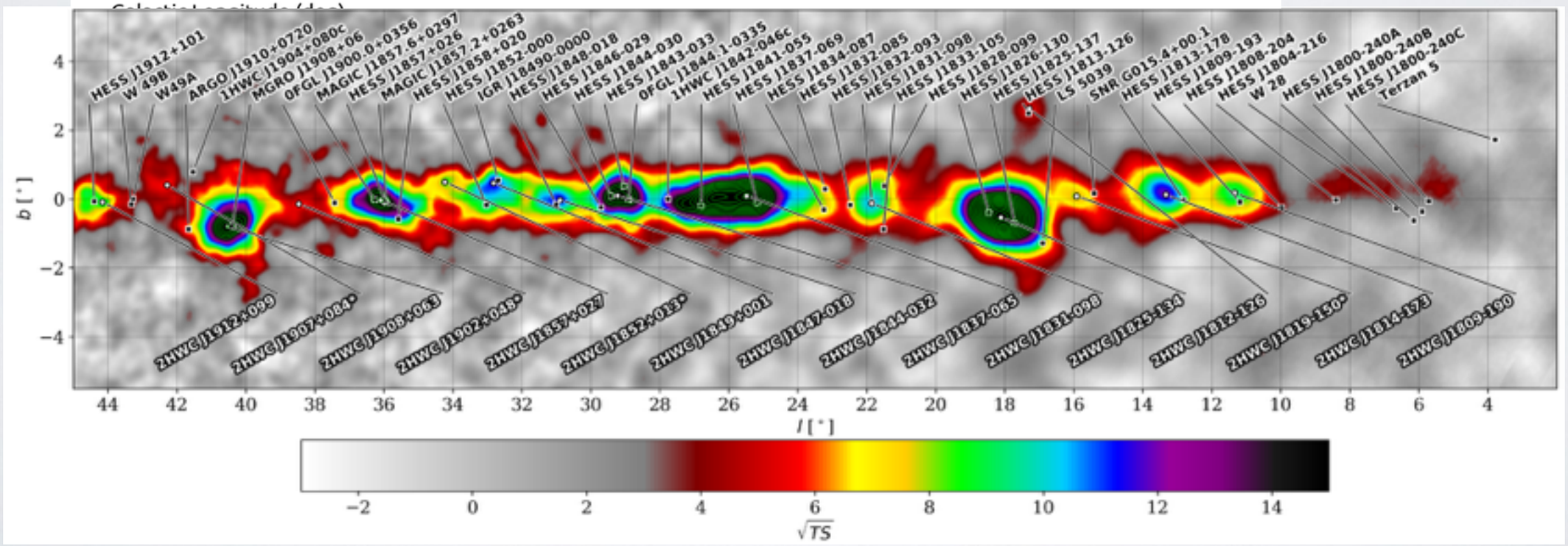




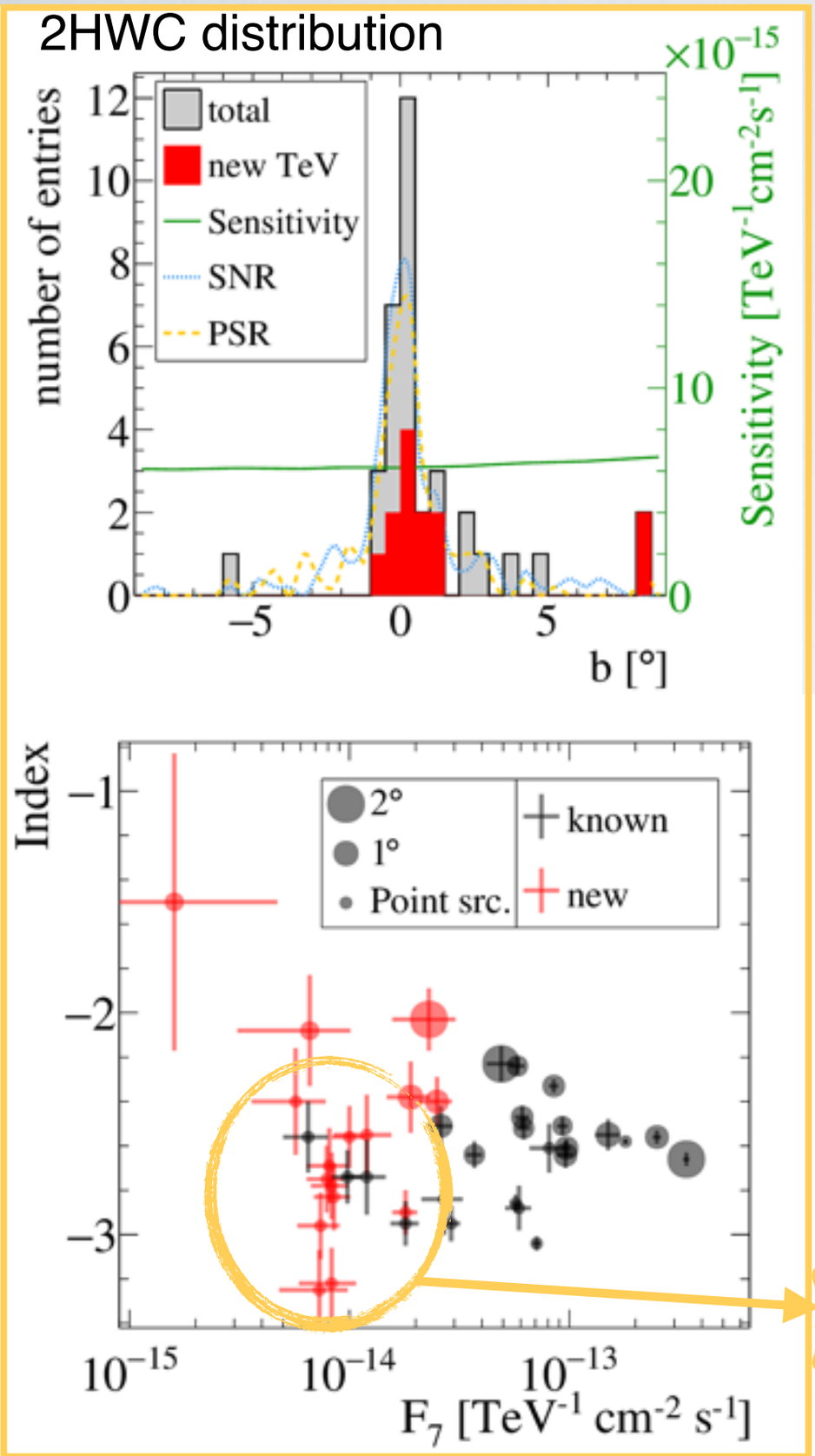


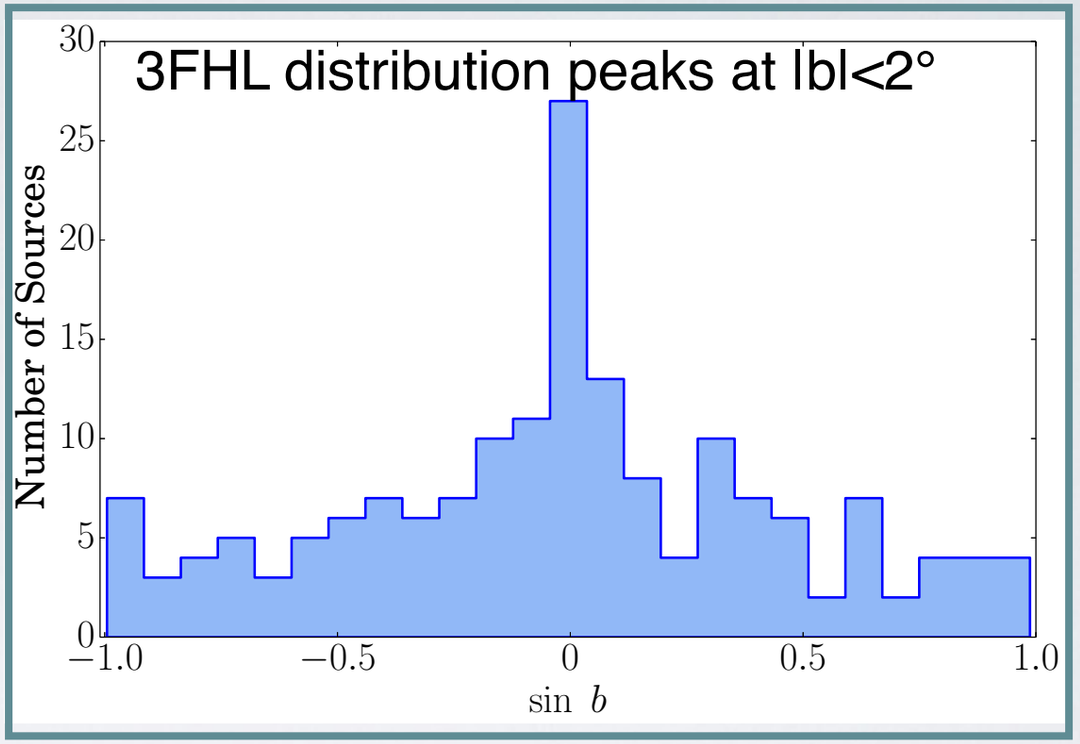

-0°
-6°

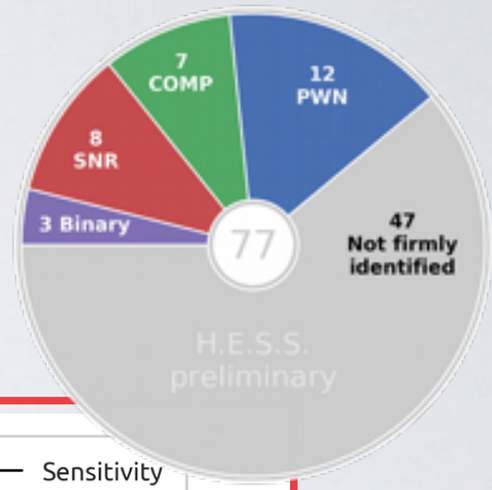

HESS, ICRC 2015
44 42 40 38 36 34 32 30 28 26 24 22 20 18 16 14 12

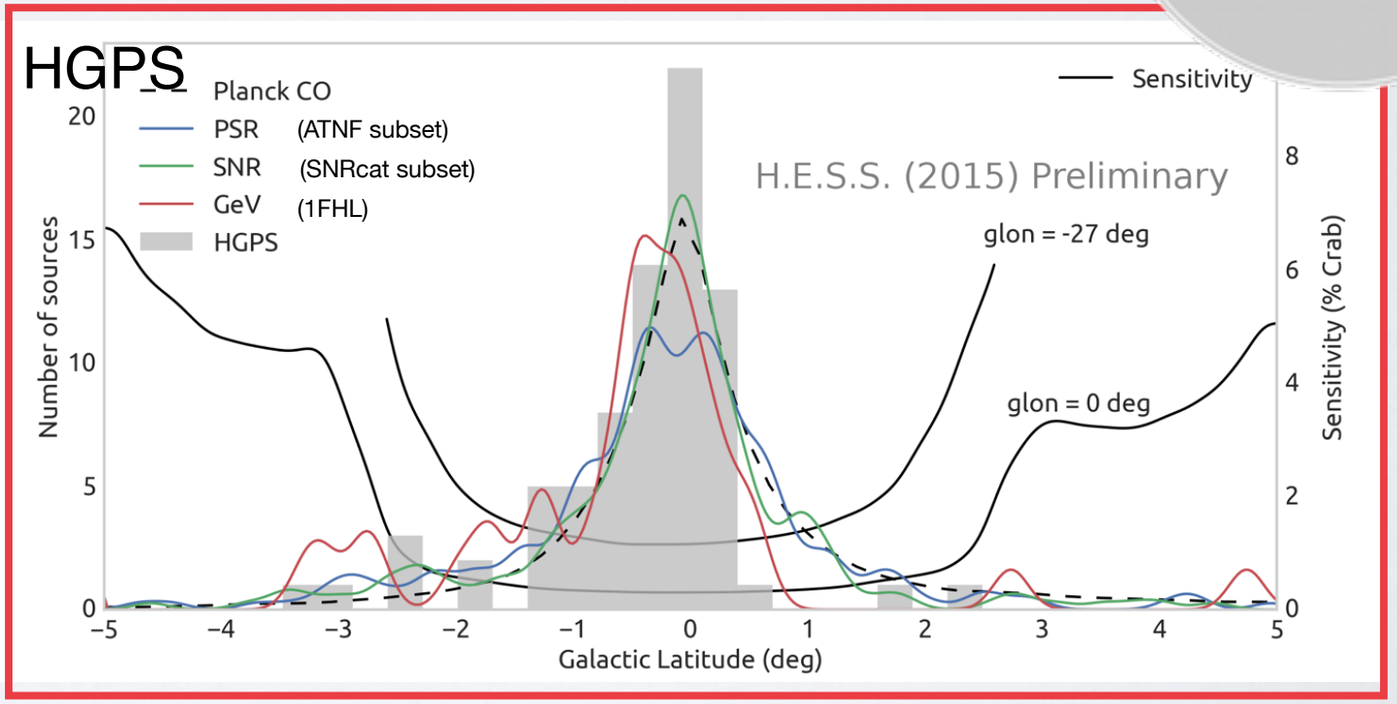

HESS J1912+101
W 49B
W49A
ARGO J1910+0720
1HWC J1904+080c
MGRO J1908+06
OFGL J1900.0+0356
MAGIC J1857.6+0297
HESS J1857+026
MAGIC J1857.2+0263
HESS J1858+020
HESS J1852-000
IGR J18490-0000
HESS J1848-018
HESS J1846-029
HESS J1844-030
HESS J1843-033
OFGL J1844.1-0335
1HWC J1842-046c
HESS J1841-055
HESS J1837-069
HESS J1834-087
HESS J1832-085
HESS J1832-093
HESS J1831-098
HESS J1833-105
HESS J1828-099
HESS J1826-130
HESS J1825-137
HESS J1813-126
LS 5039
SNR G015.4+00.1
HESS J1813-178
HESS J1809-193
HESS J1808-204
HESS J1804-216
W 28
HESS J1800-240A
HESS J1800-240B
HESS J1800-240C
Terzan 5
2HWC J1912+099
2HWC J1907+084*
2HWC J1908+063
2HWC J1902+048*
2HWC J1857+027
2HWC J1852+013*
2HWC J1849+001
2HWC J1847-018
2HWC J1844-032
2HWC J1837-065
2HWC J1831-098
2HWC J1825-134
2HWC J1812-126
2HWC J1819-150*
2HWC J1814-173
2HWC J1809-190
b [°]
l [°]
√TS

Galactic Plane Source Distribution





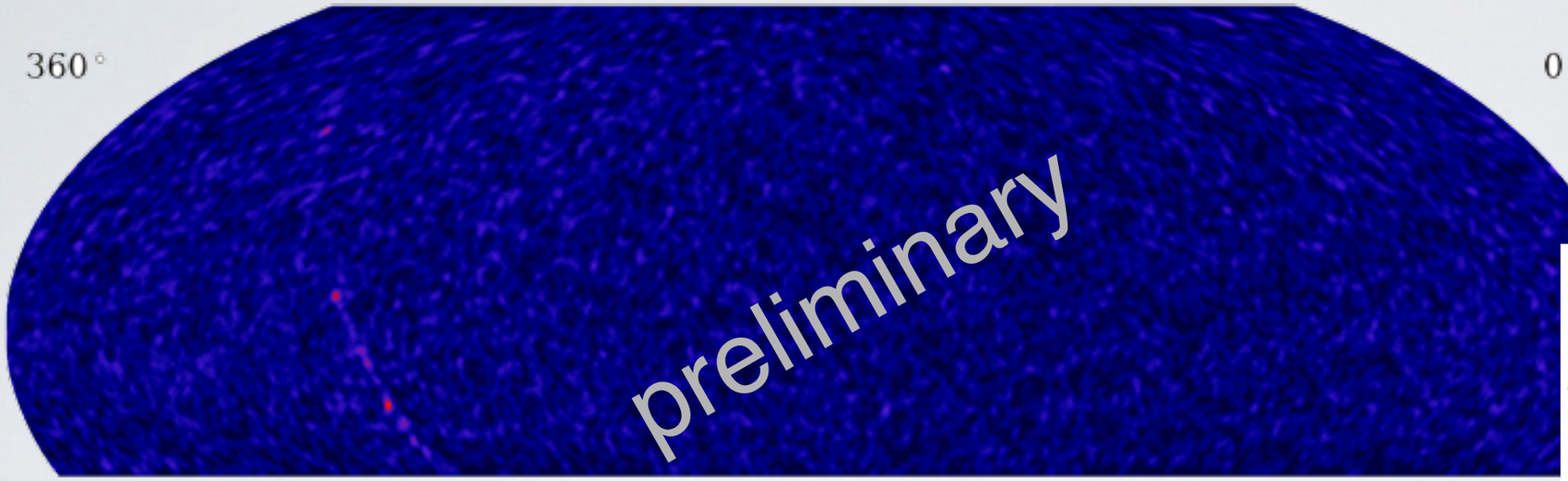


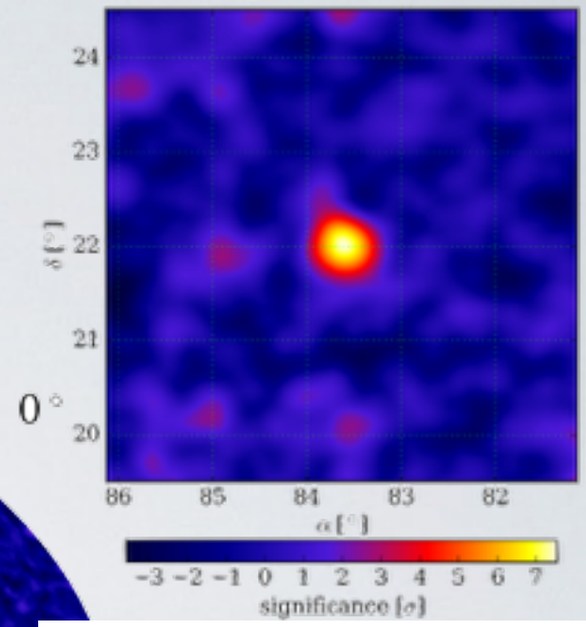


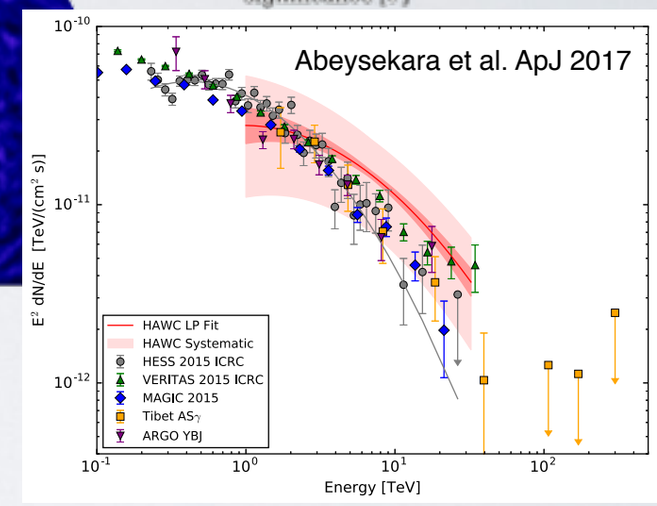
Good candidates for follow-up by pointing instruments.

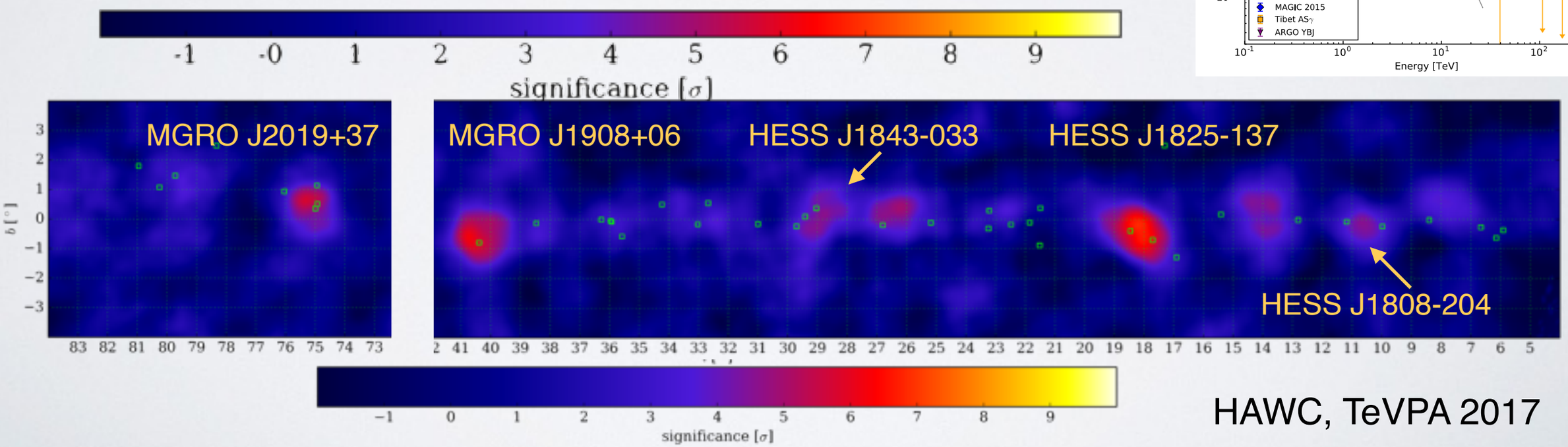
Galactic Plane at >50 TeV

1deg extended map at >50 TeV





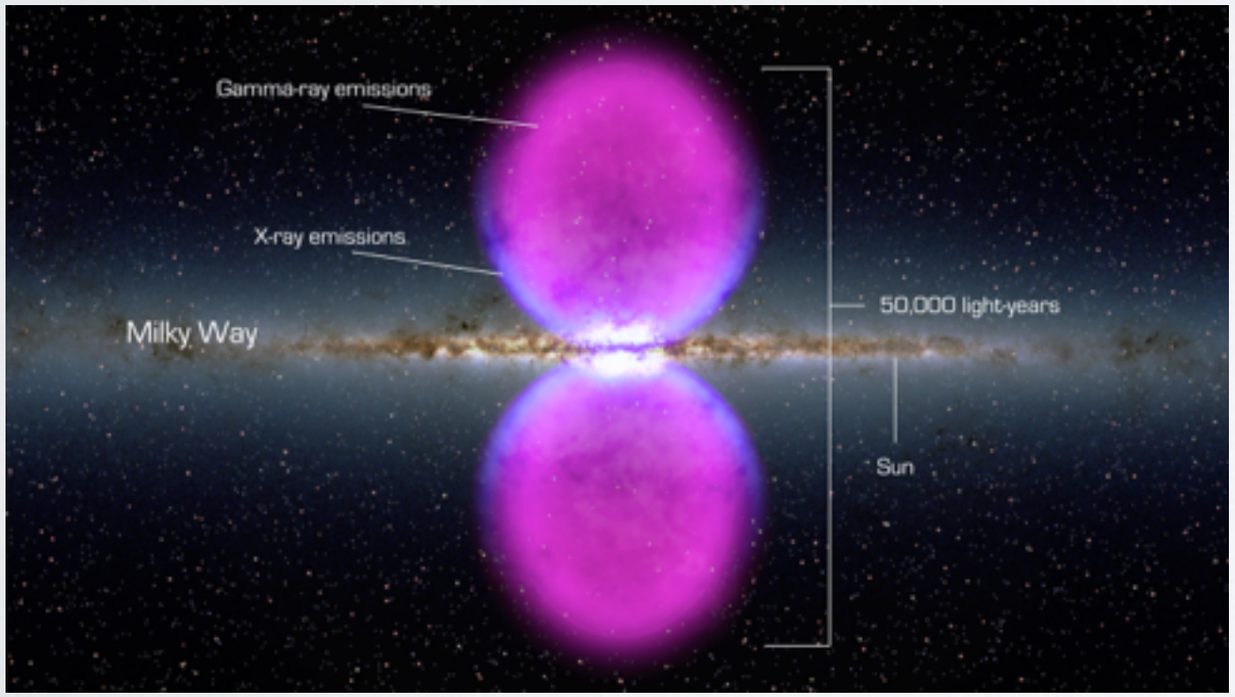


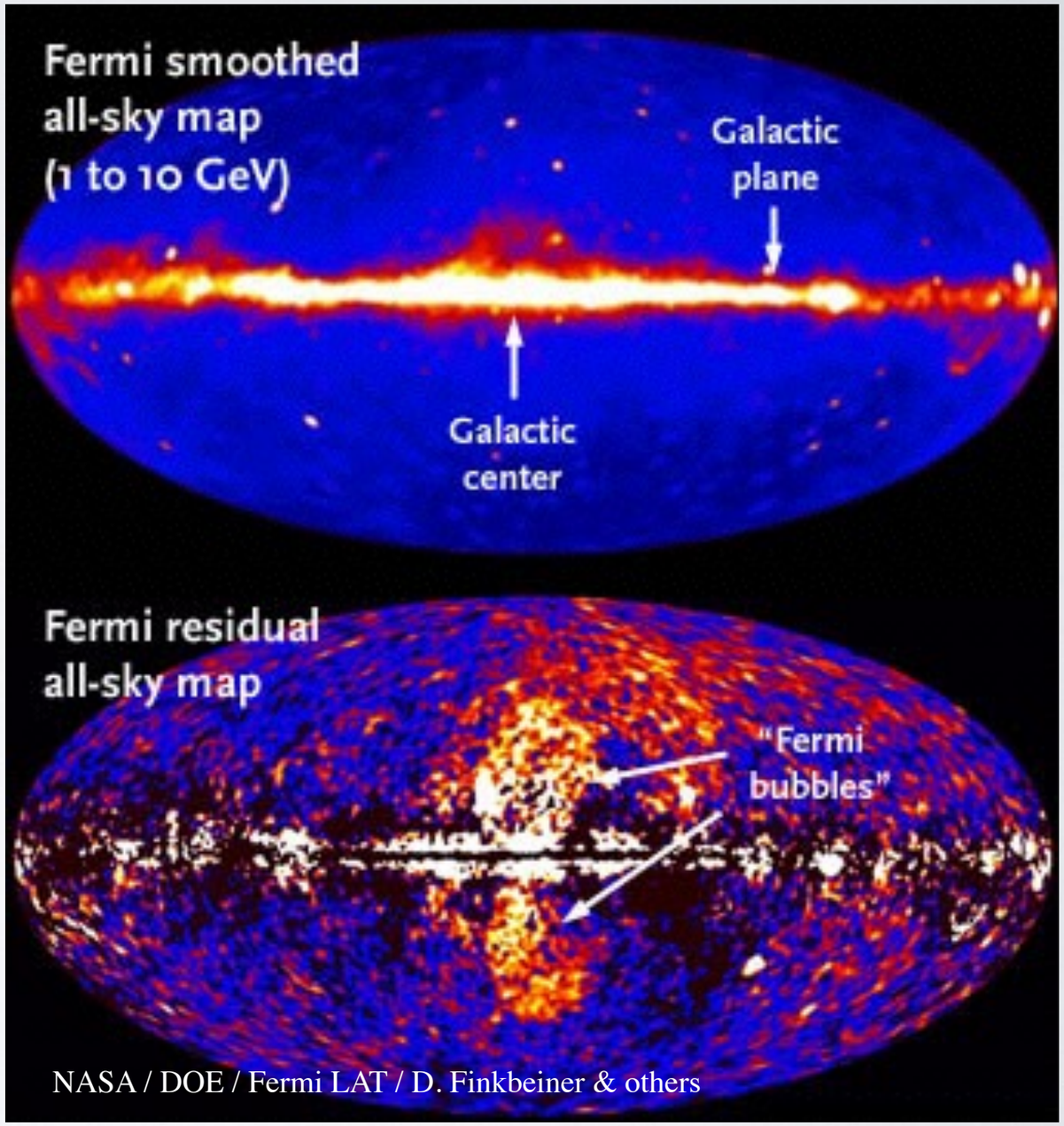


HAWC, TeVPA 2017

Large-scale structures
e.g. Fermi Bubbles

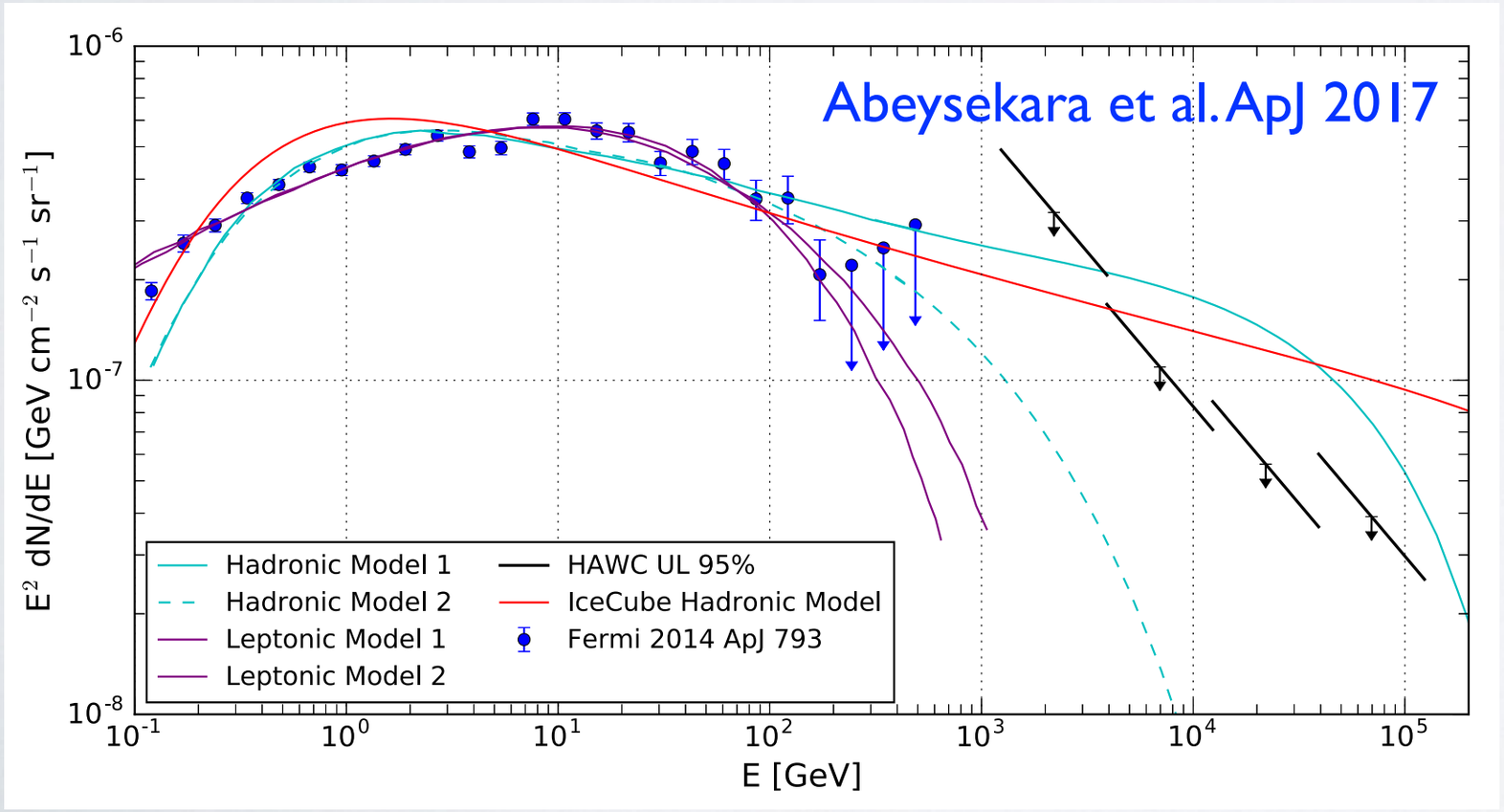
- Large scale, non-uniform structures extending above and below the Galactic center.
  - Edges line up with X-ray features.
  - Correlate with microwave excess (WMAP haze)
  - Both hadronic and leptonic model fit Fermi LAT data. Leptonic model can explain both gamma ray and microwave excess.

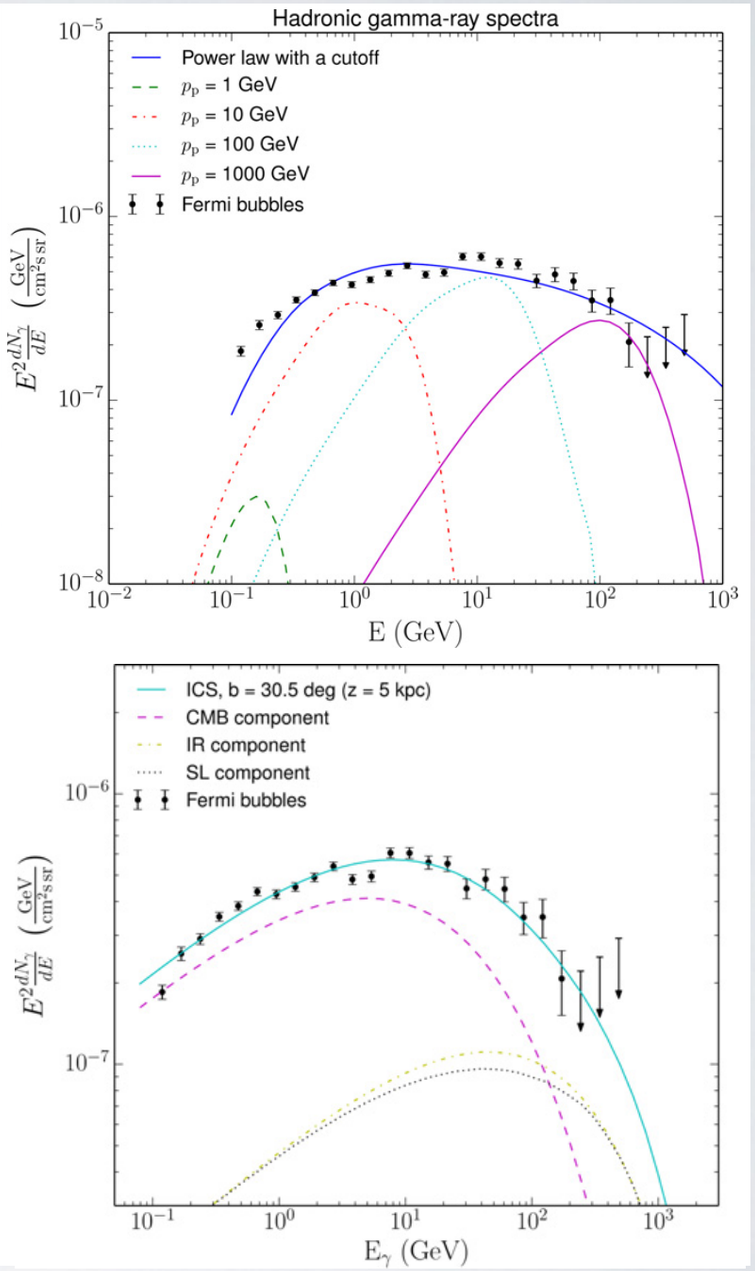




Large-scale structures e.g. Fermi Bubbles

- Hadronic model:
  - cosmic ray interacting with interstellar matter
  - hard to explain microwave haze
- Leptonic model:
  - electron population produced by outflow from Galactic center, or reaccelerated inside the bubble
- First limits in TeV, **hard spectrum is highly unlikely.**

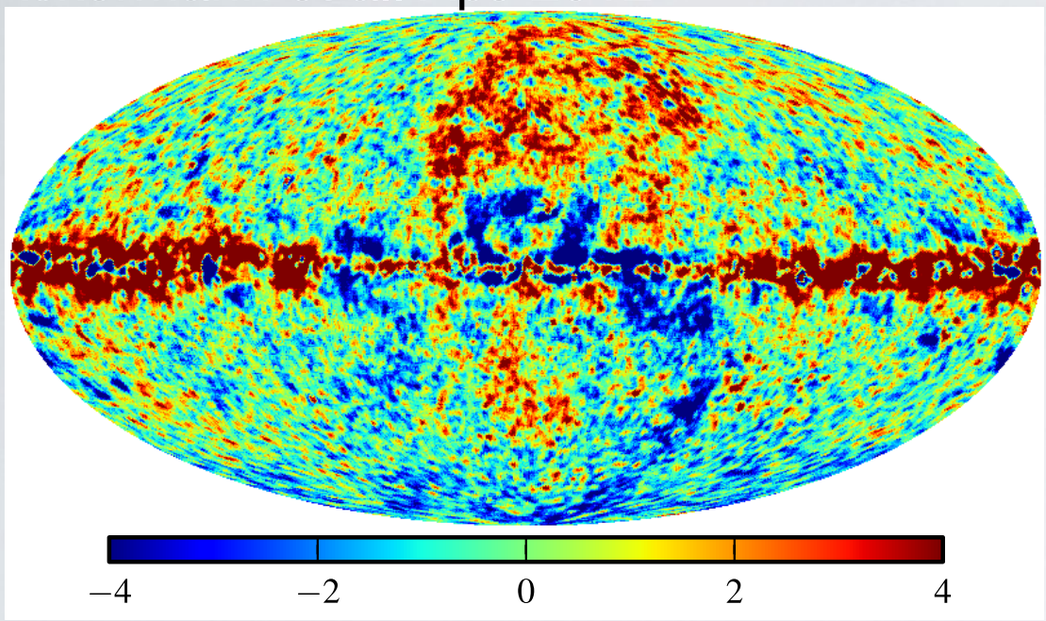


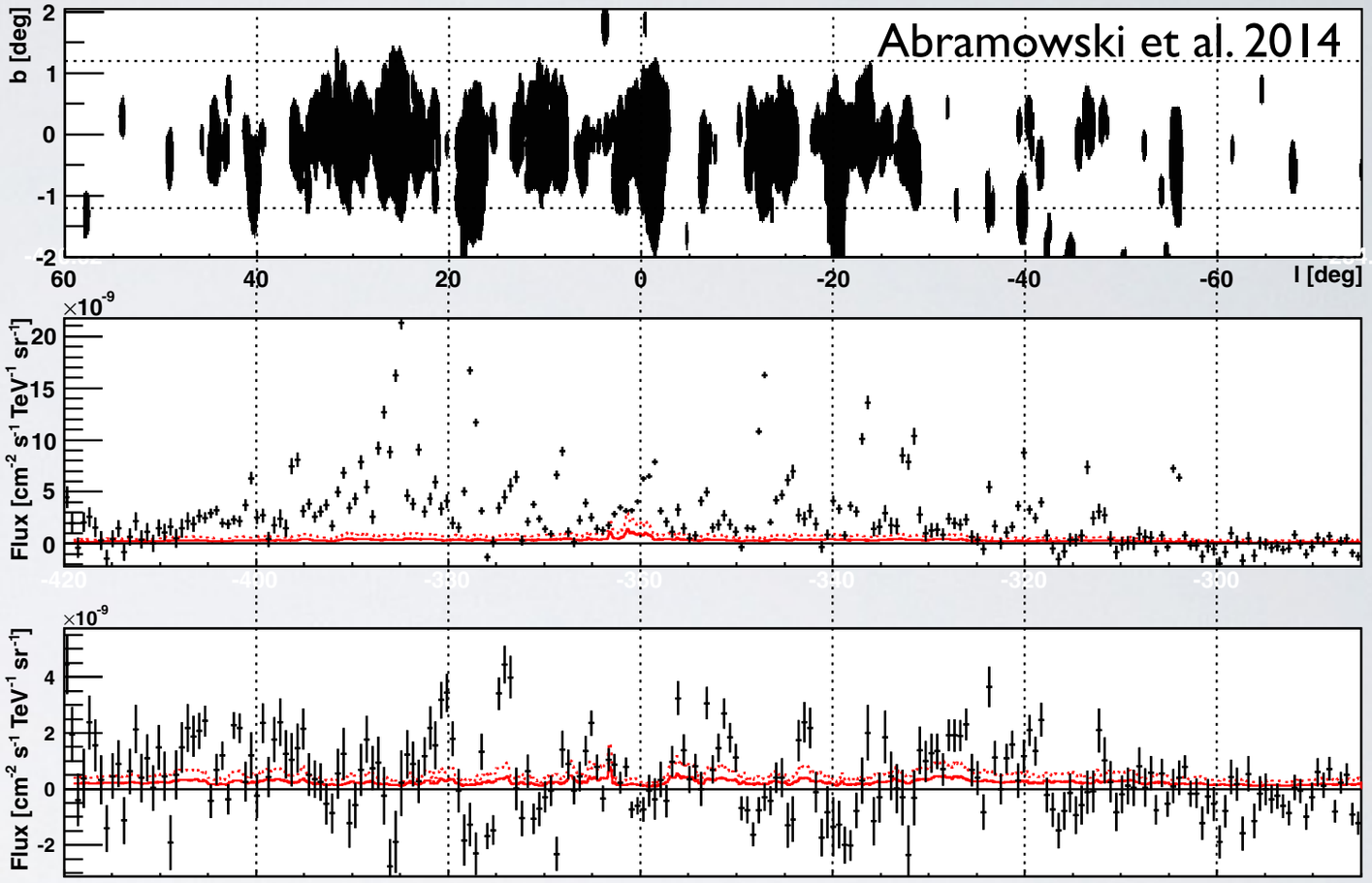


Ackermann et al. ApJ (2014)

Galactic Diffuse Emission

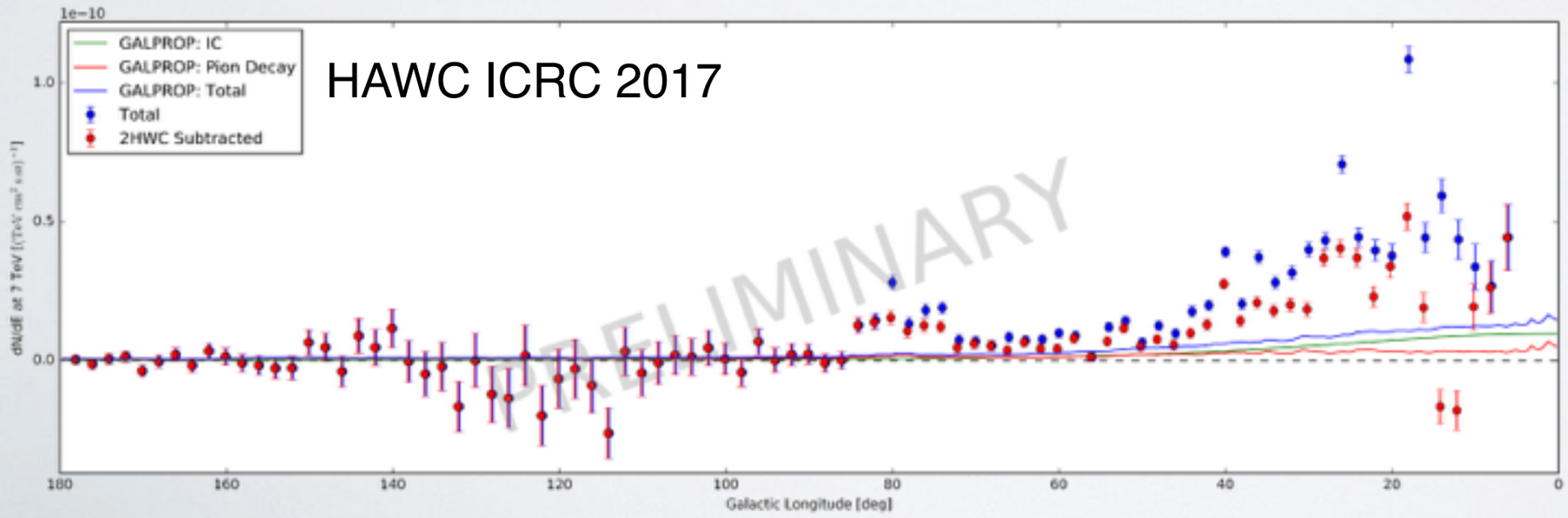
Ackermann et al. ApJ 2012





Diffuse contributions:

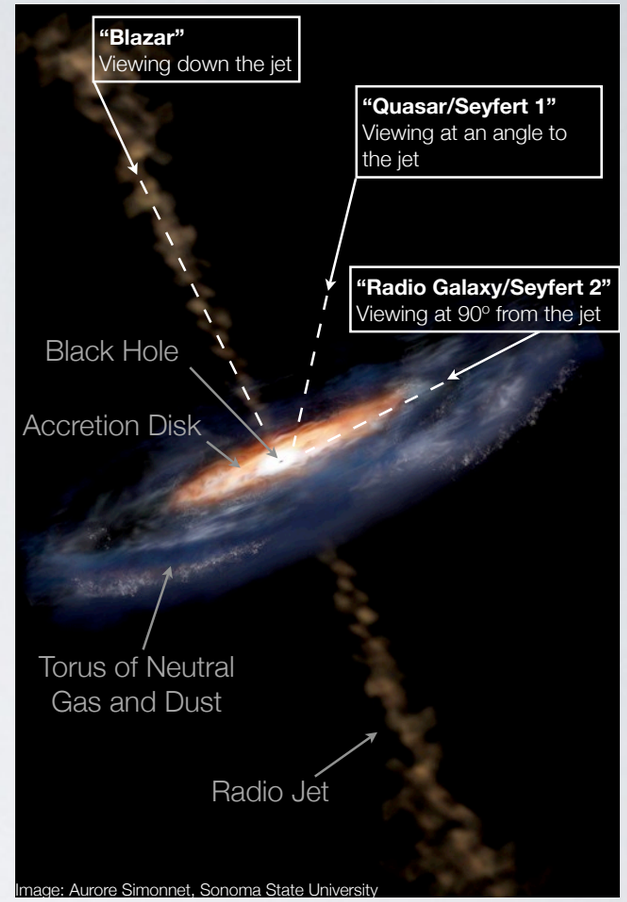
- Cosmic-ray interactions
  - molecular clouds
  - interstellar gas
- Inverse Compton
- **Unresolved sources**



Ongoing work to model extended and multiple sources.

Extragalactic: Active Galactic Nuclei

- Majority (>1000) of 3FHL are associated with another galaxy
- ~75 TeV AGNs
- Topics:
  - flares
  - extragalactic background light
  - intergalactic magnetic field
- HAWC consistently detects and monitor Mrk 421 and Mrk 501, and presented upper limits to 132 sources selected from 3FHL with z<0.3 [ICRC 2017].

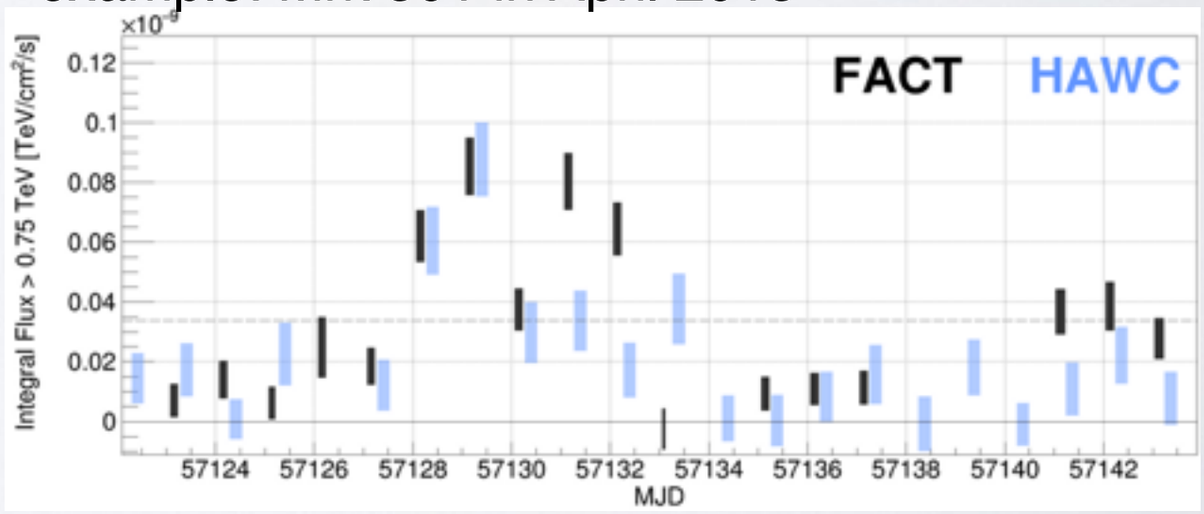


HAWC transient monitoring

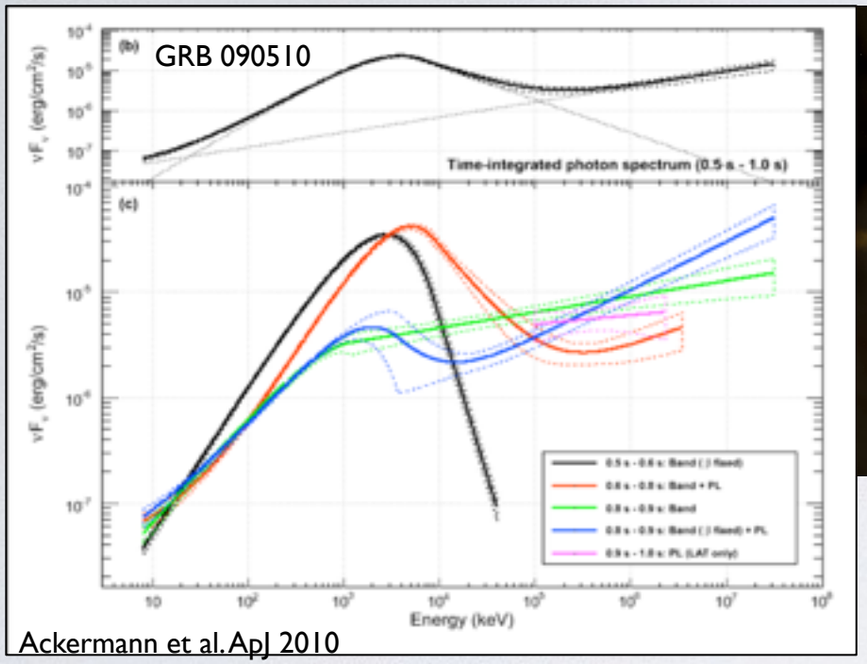
- rapid flare monitor: 2min — 10hr
  - fast rising flux from known blazars.
- daily maps: ~6hr
  - flux in every point in all visible sky.

Joint monitoring with FACT

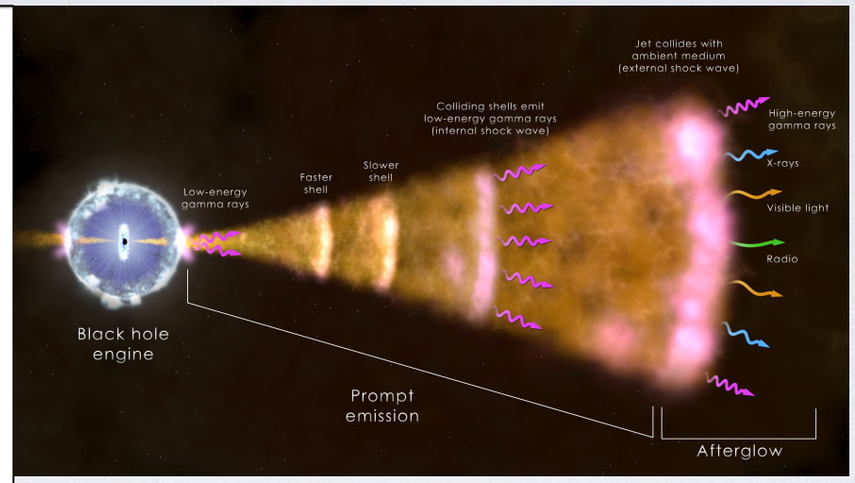
example: Mrk 501 in April 2015

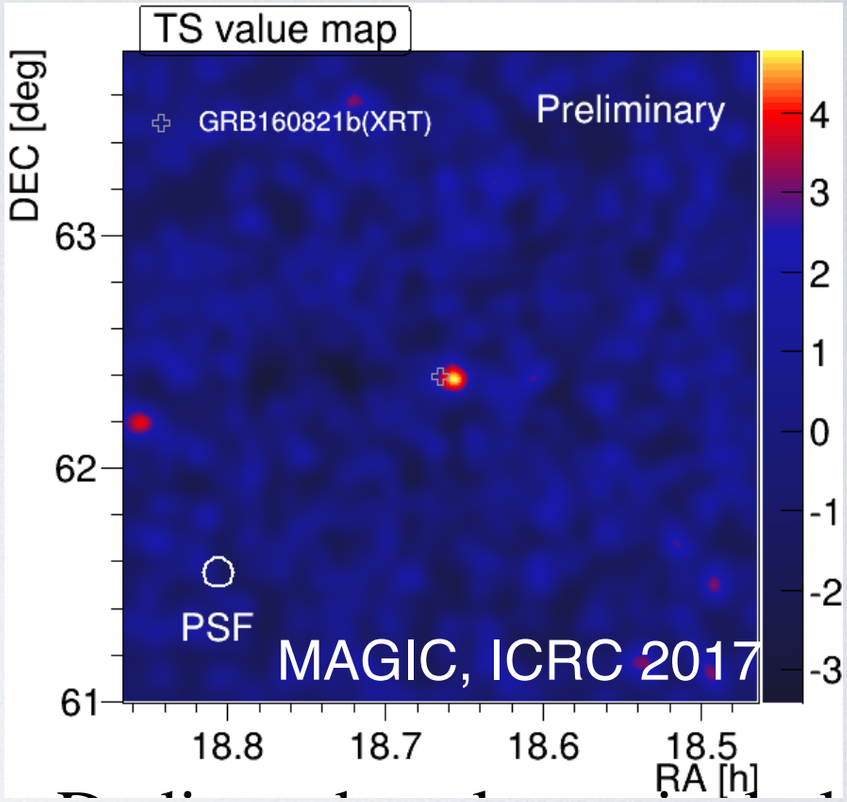


Transient Search: Gamma-Ray Bursts



Ackermann et al. ApJ 2010





Talk by S. Dichiara Tue, 17 Oct

HAWC

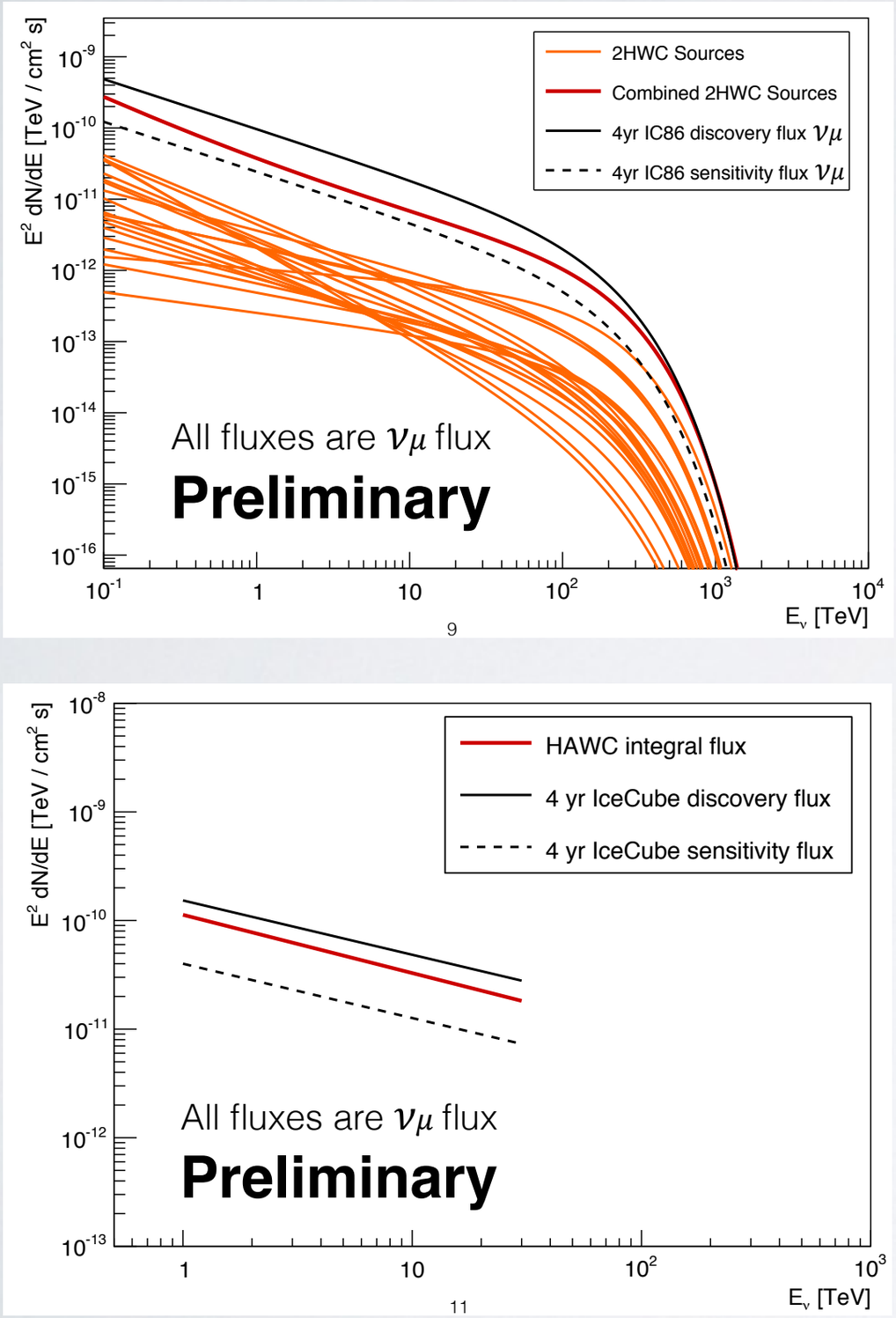
- triggered GRB search: 0.2s — 300s
  - external alerts, searching for temporal and spatial coincidence.
- blind GRB-like search: 0.2s — 10s
  - search entire FOV for burst events.
- ~4 seconds online analysis latency
  ➔ issue fast GRB and transients alerts.

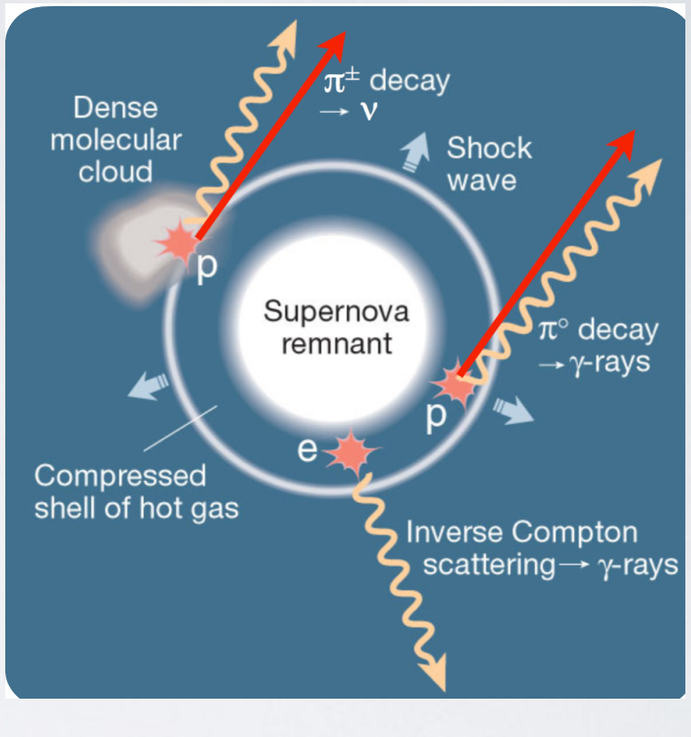
GRB 160821B

- z=0.16
- MAGIC observed ~3σ excess >500GeV
  - exposure up to 4hr after T0.
  - centroid offset from nominal GRB position.

Galactic Origin of IceCube Neutrinos?

IceCube/HAWC, TeVPA 2017

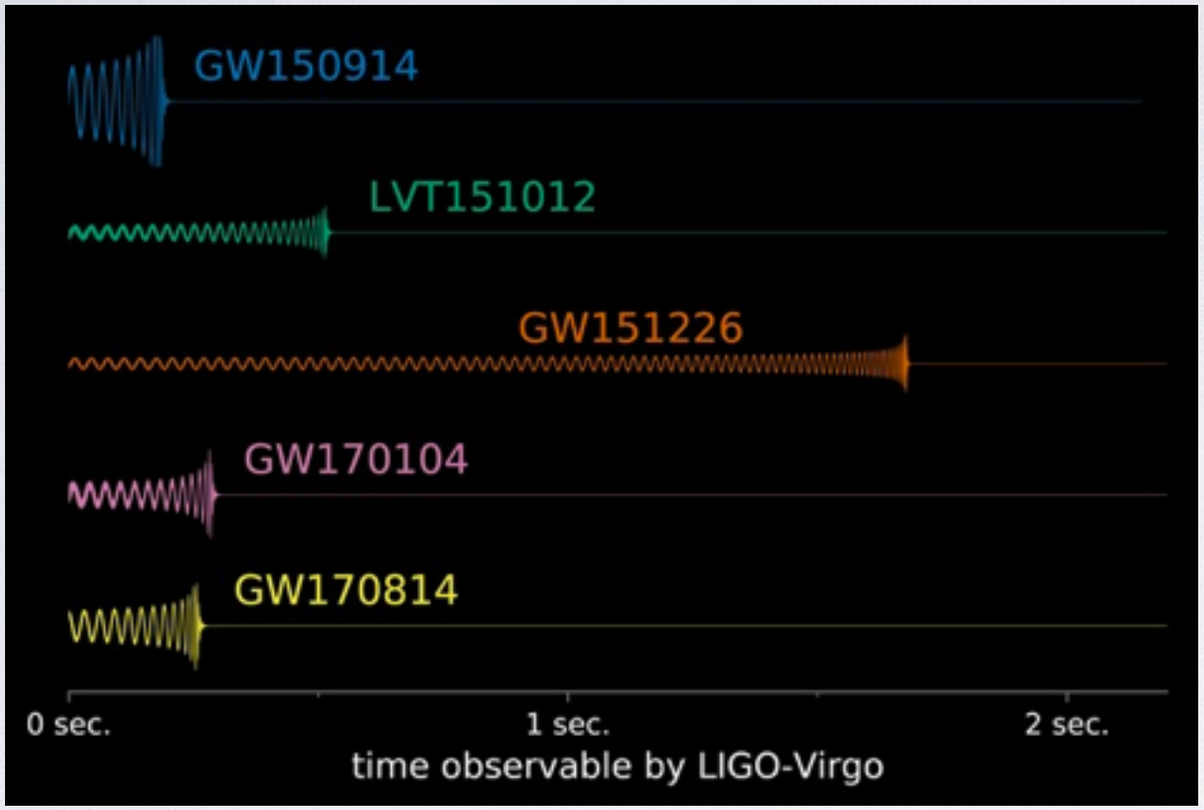




- PeVatrons producing pionic gamma rays up to 300 TeV and neutrinos up to 150 TeV.
- Stacked analysis using 2HWC sources (excluding PWN) estimate HAWC Galactic plane emission accounts for ~5% of IceCube all-sky flux.
- Template analysis using HAWC flux map of Galactic plane.

LIGO Follow-up

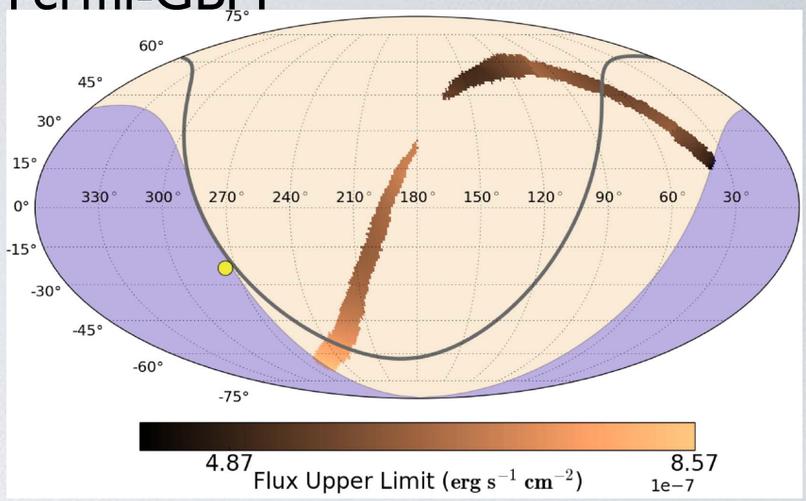
Courtesy Caltech/MIT/LIGO Laboratory

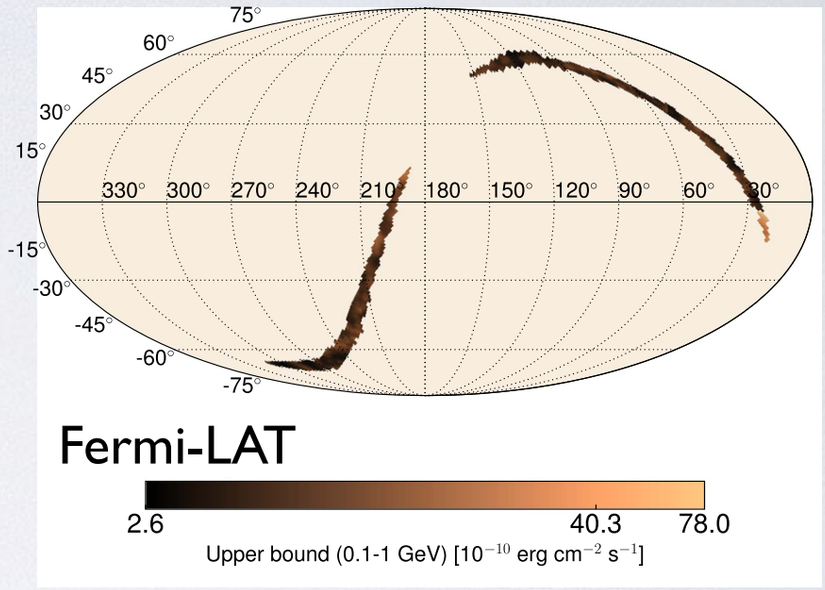


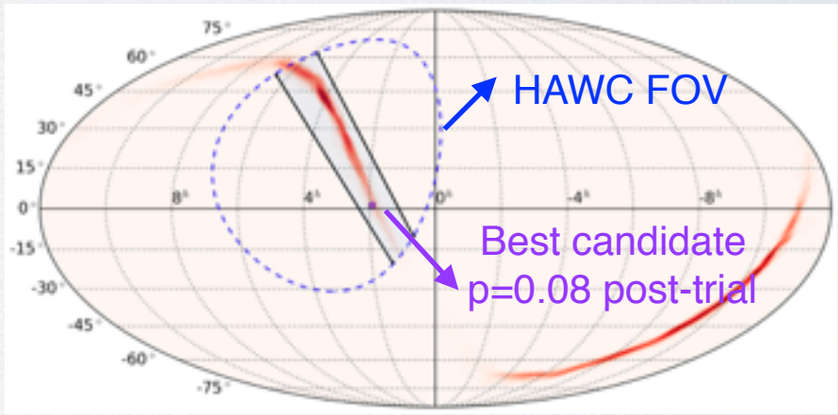
GW151226:

- 2015 Dec 26 03:38:53.6 UTC
- z=0.09 +0.03 -0.04
- 14.2$M_\odot$ + 7.5$M_\odot$ ➡20.8$M_\odot$

Fermi-GBM



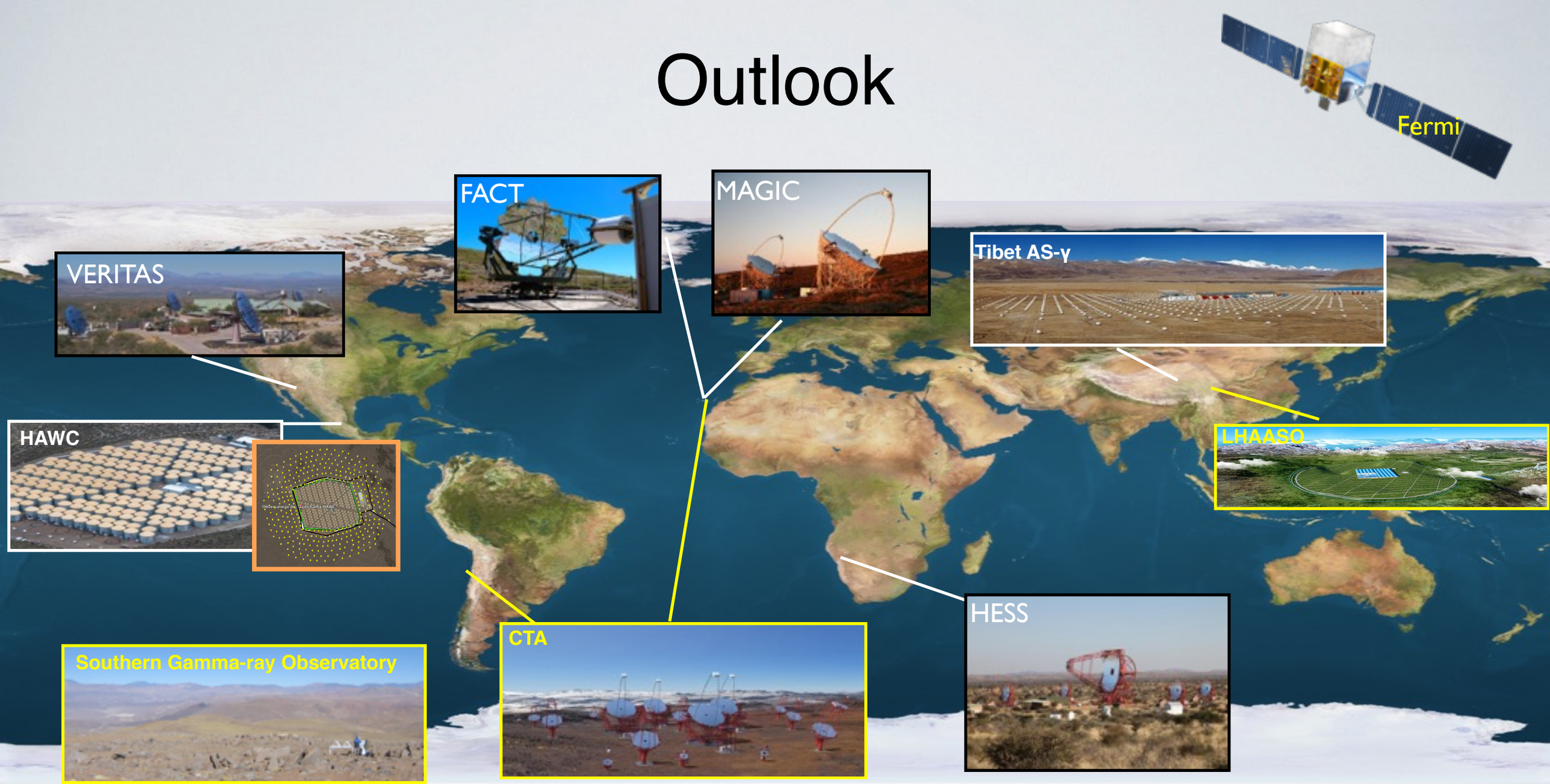




Best candidate 9.98s after LIGO trigger

- post-trial p-value 0.08, consistent with background.

Outlook



- The gamma-ray sky is currently well-monitored with good survey coverage.
- Many instruments from different waveband/messenger (X rays, gamma rays, neutrinos, gravitational waves) available for simultaneous observations.
- Both wide-field and pointing instruments in development and coming online in the next decade.